DESIGN OF A NEW GRAB BAR FOR OLDER ADULTS

A Thesis
Presented to
The Academic Faculty

by

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In Partial Fulfillment
of the Requirements for the Degree
Master of Industrial Design in the
School of Industrial Design

Georgia Institute of Technology
August 2013

DESIGN OF A NEW GRAB BAR FOR OLDER ADULTS

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Date Approved: April 30, 2013

ACKNOWLEDGEMENTS

I wish to thank Jon Sanford, my advisor, for his knowledge, guidance and patience during the process of this project. I want to thank Wayne Li and Randy Bernard for their feedback and help. Thanks to Russell Taylor, my engineer, for his support and effort that he put in this project, and to people at APWL who helped me machine the prototype. I specially thank people who helped me recruit subjects for user testing, for confidential reasons I cannot put their names here. Lastly I would like to thank my parents and friends, without whose support and encouragement I would not be here.

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LIST OF ABBREVIATIONS

ADA	Americans with Disabilities Act
ADAAG	ADA Accessibility Guidelines
GB	Grab Bars
W	Wheelchair
A	Armrests
SH	Short Handles
CATEA	Center for Assistive Technology and Environmental Access

SUMMARY

Toilet grab bars were intended to facilitate independent and safe toilet transfer for people with different abilities. However, standard grab bars require too much effort from older adults who typically transfer to the toilet in a standing position rather than a sitting position. Among existing grab bars, grab bars on both sides of the toilet worked best for older adults because they allowed older adults to use both arms to get on and off the toilet. However, based on our observation, these grab bars were not effective to assist older adults to get in and out of the wheelchair. Additionally, these grab bars are too far apart that older adults have to use their shoulders rather than arms, which arise problems because shoulder are typically weaker than arms. This study intends to solve this problem by developing a new grab bar which would be safer, easier and more comfortable to use. Based on the literature review, analysis of existing grab bars and observation, a new concept of grab bars was generated and a functional prototype was constructed for user testing. The prototype was proved to be safe, easy and comfortable to use in the entire transfer process and it reduced the use of wheelchairs as well.

CHAPTER 1

INTRODUCTION

Problem Statement

Older adults who use mobility aids have different clinical conditions from younger wheelchair users, so they transfer on and off the toilet differently. Older adults typically transfer on and off the toilet from a standing position rather than a sitting position. When they transfer between a wheelchair and a toilet, they stand up from the wheelchair and sit down on the toilet, and then after they finish toileting, they stand up from the toilet and sit back in to the wheelchair.

Sanford, Echt and Malassigne (1999) found that grab bars that are commonly used to assist toilet transfer were originally designed to help people who slide on the toilet from a sitting position. These grab bars do not work so well for facilitating standing transfers. Other grab bars which can provide help from both sides of the toilet worked better than grab bars on only one side of the toilet, but older adults used the wheelchair instead of the grab bars when they got out of and got back into the wheelchair, which would cause safety problem if the wheelchair was unlocked. Additionally, the distance between these grab bars was too wide, so older adults used their shoulders instead of their arms to pull themselves up from a sitting position. However shoulders are typically weaker than arms to generate force.

The Target Users

The older population will continue to grow significantly in the future and more people will age into disability. It was predicted that the number of persons 65 years old and older would increase to 54.8 million in 2020 and 72.1 million in 2030, comparing to 40.2 million in 2010 (U.S. Census Bureau, 2008). In 2007, Over 25% of community-

resident and 83% of institutionalized Medicare beneficiaries over age 65 had difficulty performing one or more activities of daily living (ADLs), including getting around inside the home, getting in or out of bed or a chair, bathing, dressing, eating and toileting (Greenberg, 2009). It was also reported that in 2008, 24.7% of older persons had ambulatory difficulty (Brault, 2009).

Data from a national survey (Sanford, Echt and Malassigne, 1999) revealed that more than 80% of the older respondents (aged 55+ years) had age-related conditions such as hemiplegia, poor balance and arthritis. And 46.5% of the older respondents in this survey used a wheelchair some of the time, and used walking aids as well, compared to only 5.2% of the older respondents who used a wheelchair all of the time. So it could be concluded that although they need wheelchairs or walking aids for long time mobility these older respondents had the ability to bear the weight in a standing position.
In the same survey, Sanford, Echt and Malassigne (1999) found that 88% of the older respondents who used wheelchairs stood to get onto the toilet. In the laboratory study (Sanford, Echt and Malassigne, 1999), when older subjects transferred to the toilet, they all stood up from the wheelchair and then sat down on the toilet. When they transferred back to the wheelchair, they stood up from the toilet to a standing position, and then sat back into the wheelchair.

Grab bar requirements

Toilet grab bars required by the Americans with Disabilities Act Accessibility Guidelines (ADAAG)) include two configurations: one for non-ambulatory individuals (Figure 1.1(a) and Figure 1.2) and the other for ambulatory individuals (Figure 1.1(b) and Figure 1.3). The non-ambulatory configuration was designed for people who cannot stand and have to slide onto the toilet from the side. The ambulatory configuration was designed for people who can stand and sit down on the toilet. In the original guidelines enforced from 1991 to 2010 there was no ambulatory configuration. Although the

ambulatory configuration was added in the 2010 revision of ADAAG, unlike the mandatory non-ambulatory configuration, the ambulatory configuration is not mandatory and can only be used when the required number of non-ambulatory toilet stalls have been built (in new construction) or if it is technically infeasible to build in existing construction. The difference between the ADA non-ambulatory and ambulatory grab bar configurations is that the ambulatory configuration has grab bars installed on both sides of the toilet, whereas the non-ambulatory configuration has one grab bar on the side of the toilet and the other on the rear wall of the toilet.

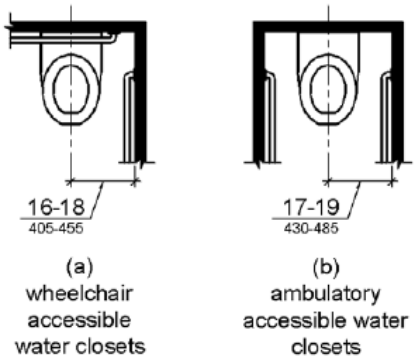


Figure 1.1 ADA grab bar configuration (Figure 604.2 ADAAG 2010)

Figure 1.2 Toilet installed with ADA non-ambulatory grab bar configuration

Figure 1.3 Toilet installed with ADA ambulatory grab bar configuration

ADAAG also has requirements for the position of side and rear wall grab bars. Figure 1.1 shows the standards for the distances from the center line of a toilet to the walls. This distance should be between 16 to 18 inches for a non-ambulatory configuration and 17 to 19 for a non-ambulatory configuration. Further, Grab bars should be installed in a horizontal position, 33 inches (840 mm) minimum and 36 inches (915 mm) maximum above the finish floor measured to the top of the gripping surface (609.4 Position of Grab Bars, ADAAG 2010). Figure 1.4 shows the requirement of the horizontal distance from the grab bar to the walls.

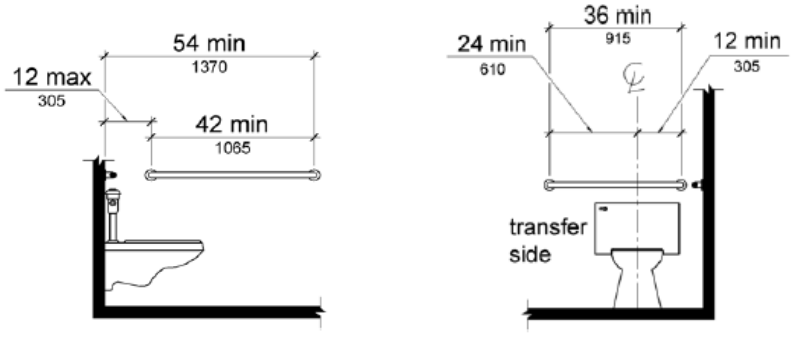


Figure 1.4 Side Wall and Rear Wall Grab Bar (Figure 604.5.1& Figure 604.5.2 ADAAG 2010)

Problems with existing grab bar requirements

In a national survey of people's use of toilet grab bars, wheelchair users who stood to the toilet responded that the ADA configuration (Figure 1.5) was the second to the most difficult grab bar configuration among the four to use (Sanford, Echt and Malassigne, 1999). In contrast, the alternative ADA grab bar configuration (Figure 1.5) was reported the easiest configuration to use. Similarly, in the laboratory study, Sanford, Echt and Malassigne (1999) found that the ADA configuration (Figure 1.6) was the most difficult configuration to use and was used least often by older adults. But the folding grab bar configuration (swing-away grab bars in Figure 1.5), which has two grab bars on both sides of the toilet, was used most often and reported the easiest to use among the four grab bar configurations tested. So it could be concluded that for older adults who stood on to the toilet, grab bars on both sides of the toilet were used much often and were rated less difficult to use than grab bar on only one side of the toilet.

However, neither the ADA grab bars nor the folding grab bars were used all the time in the laboratory study (Sanford, Echt and Malassigne, 1999), and the frequency of mobility device use was almost the same as the frequency of grab bar use in most configurations. Based on my review and analysis of the video tape records from this study, I found that when subjects got off the toilet and sat back in the wheelchair, they used the wheelchair much often than the ADA grab bars. In the folding grab bar configuration, although subjects used the folding grab bars to stand up from the toilet, when they pivoted themselves and sat back into the wheelchair, they relied on the wheelchair more often than the folding grab bars. Because wheelchairs are less stable than grab bars, the more they use the wheelchair, the more an accident might occur.

Additionally, because the distance between the folding grab bars were too wide, subjects pulled themselves up from the wheelchair or the toilet using their shoulders rather than their arms, which made it more difficult to stand up if the subjects had arthritis in their shoulder.

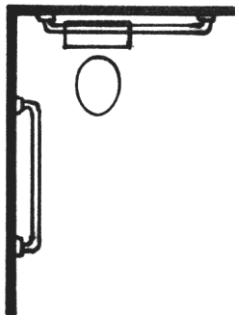
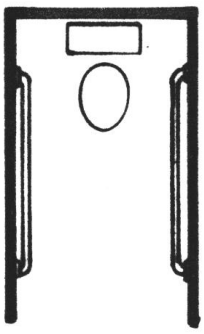
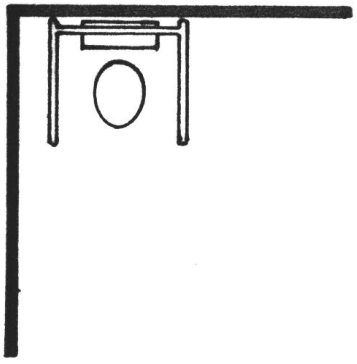
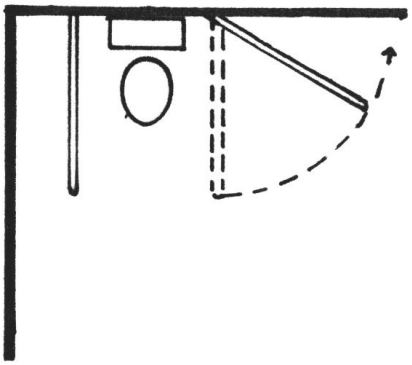
1. **ADA Configuration** (side and rear grab bars) 	2. **Alternate ADA** (2 side grab bars) 
3. **Straddle Bar** (2 side and one rear grab bar) 	4. **Swing-away** (2 side grab bars) 

Figure 1.5 Four grab bar configurations presented in the national survey (Sanford, Echt and Malassigne, 1999)

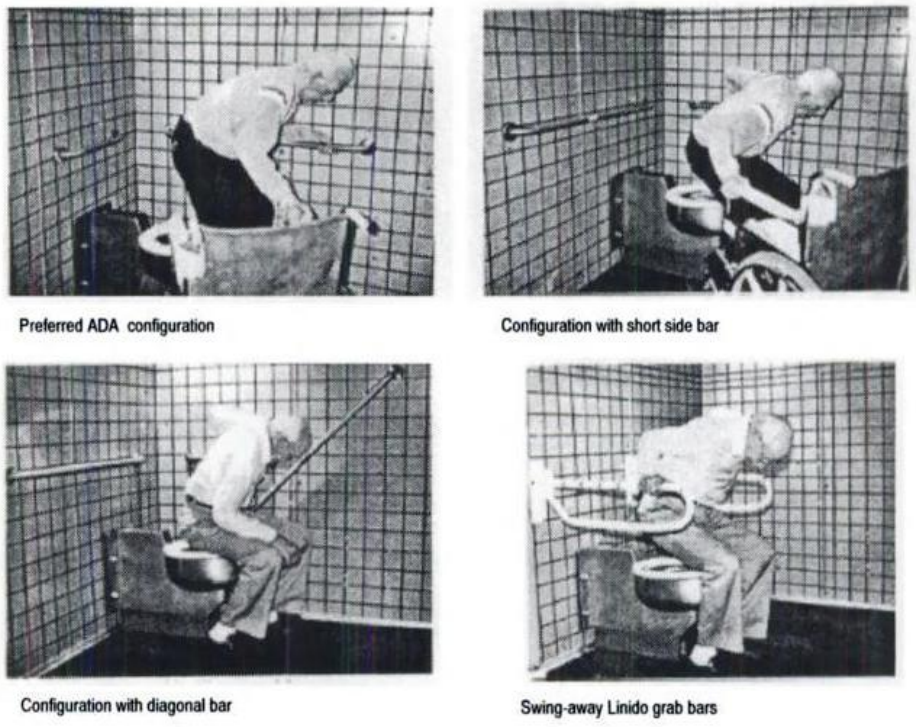


Figure 1.6 Grab Bar Configurations Tested in the laboratory study (Sanford, Echt and Malassigne, 1999)

Objectives

The objective of this project was to solve the problems (as shown below) by design, fabricate and test a new toilet grab bar that will increase independence, safety, ease and comfort of toilet transfer for older adults.

Problems:

- Use of wheelchairs
- Use of shoulders rather than arms

The specific aims of this project were to:

- Develop a new toilet grab bar for older adults who use wheelchairs, but stand to

get on and off a toilet.

- Test the new grab bar through user testing and evaluation.
- Refine the design based on feedback from potential users.

Phase I of this project focused on preparation for designing the grab bar, including:

- Identifying specific transfer problems and defining the objectives.
- Identification and evaluation of existing products.
- Observation of people using existing grab bar configurations.
- Developing design criteria.

Phase II focused on developing and refining the new design including:

- Building a functional prototype and install the prototype on the testing equipment.
- Recruiting older adults to test the prototype.
- Revising the design based on feedback from the testing.

CHAPTER 2

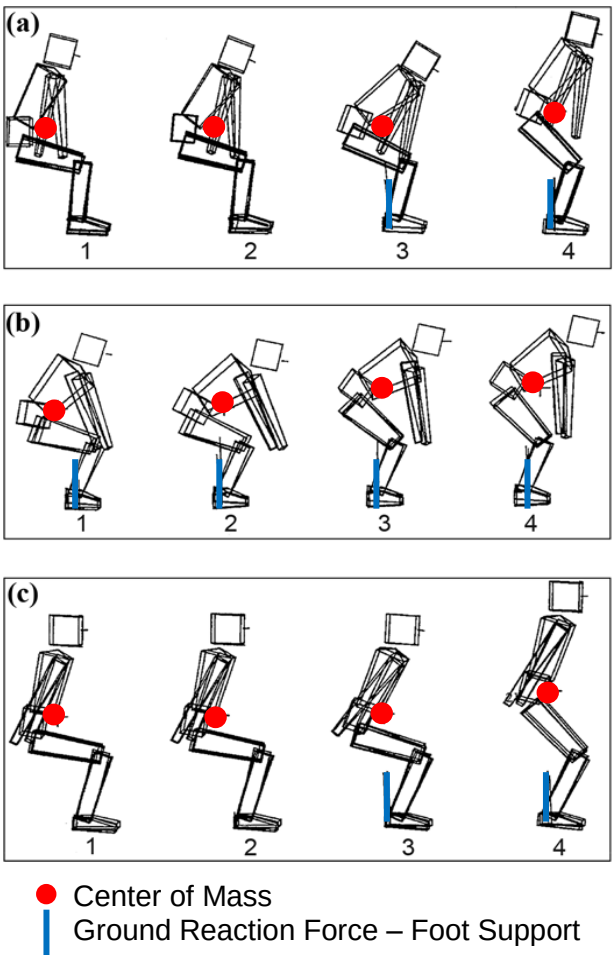
BACKGROUND

Literature Review

Biomechanics of Sit-to-stand Process

There was no work done in the study of biomechanics of toilet transfer. However, a number of researchers have looked at chair rising in the field of biomechanical engineering. Findings from these studies were useful in understanding how older adults might perform similar sit-to-stand transfer in standing transfers.

Scarborough, McGibbon and Krebs (2007) investigated chair-rise strategies in older adults with functional limitations and found that there were three different strategies performed by their subjects (Figure 2.1). Although this study concluded that the strategy shown in Figure 2.1 (a) was most preferable by their subjects, what I found valuable from this study was why the other two strategies were not commonly used. The strategy shown in Figure 2.1 (c) required the greatest knee torques due to little trunk flexion and limited anterior to vertical momentum transfer. The strategy in Figure 2.1 (b) required the back-extensor muscles act as primary movers in truck extension. Both of these two strategies did not incorporate the use of both upper and lower body in the optimal way as the strategy in Figure 2.1 (a).



Trunk flexion → Thigh extension + Trunk extension

Optimal use of both upper and lower body

Dominant Trunk flexion

Require back extensor muscles act as primary movers

Dominant Vertical Rise

Require greatest knee torques

1 = lift off
2 = maximum anteroposterior linear momentum
3 = maximum trunk flexion
4 = maximum vertical linear momentum

Figure 2.1 Sit-to-stand Strategies performed by older adults (Scarborough, McGibbon and Krebs, 2007)

In the Scarboroug, McGibbon and Krebs study, all subjects were assigned to sit on a knee-high, armless chair and stood up without any other arm support. However, other studies mentioned that the use of armrests decreased necessary knee forces (Seedholm and Terayama, 1976) and knee and hip movements (Burdett, Habasevich and Pisciotta, 1985) during the sit-to-stand process. So the chair rising strategies performed without using any arm support may not be the same with strategies using armrests.

In fact, Alexander (1991) compared the chair rising strategy performed by older adults with differing functional abilities (Figure 2.2).The results showed that compared to older adults who had stronger lower body strength and were able to stand without the use of armrests, older adults who were unable to stand up without using the armrests took significantly longer time to rise from the chair, extended their thighs significantly less, flexed their trunks significantly more, and used significantly larger ratios of armrest-force-to-body-weight (Figure 2.3 and 2.4). Their body segment rotations and entire posture change in the standing process was similar to Figure 2.1 (a) and (b) in the Scarborough, McGibbon and Krebs study, but they put their hands on the hand handles (Figure 2.2).

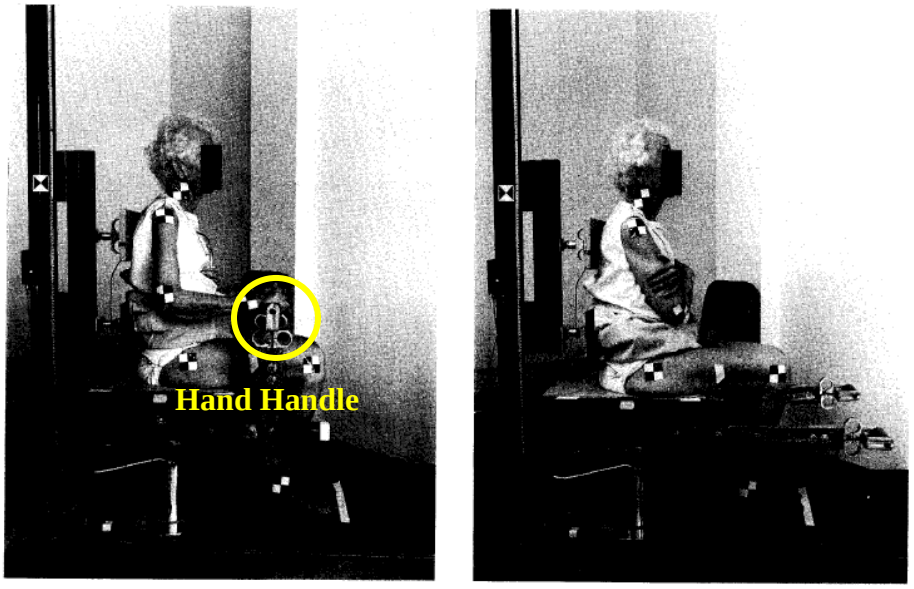


Figure 1. Subject sitting in the instrumented chair. The initial configuration shown is that for rising With Hands (A, left) and for rising Without Hands (B, right). The target markers were used in the measurement of the body segment rotations that occurred during the rise.

Figure 2.2 Subject sitting in the instrumented chair for rising with hands (left) and without hands (right) (Alexander, 1991)

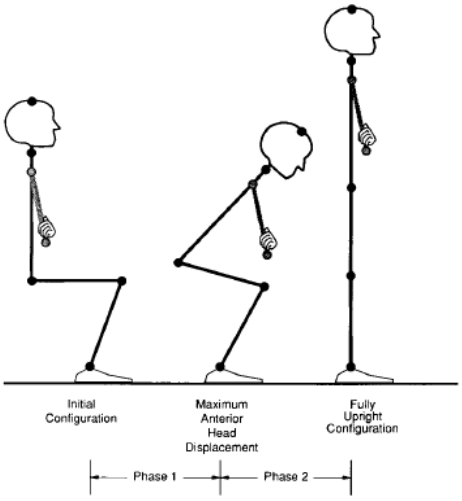


Figure 2.3 Process of rising

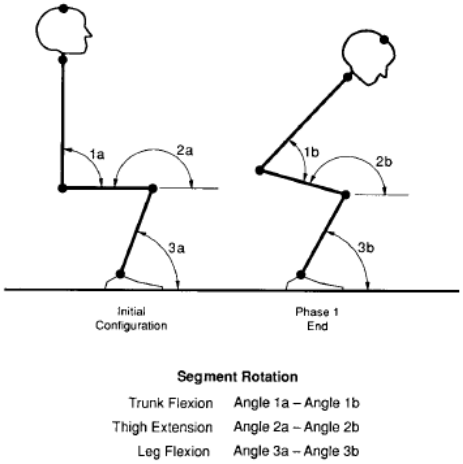


Figure 2.4 Body segment rotation

Alexander (1991) also introduced two biomechanical requirements for rising from a chair: one is to bring the center of body mass at the seat horizontally to within the area of foot support, the other is to develop the joint torque strengths needed for the rise. The degree to which the mass center is centered over the foot support area is a measure of postural stability (Alexander, 1991). In Scarborough, McGibbon and Krebs' (2007) study, people using strategy in Figure 2.1 (c) would be more likely to encounter a sit back

failure because they placed their center of gravity posterior to the ankle joint throughout the majority of the chair rising time; for people using strategy in Figure 2.1 (b), they would be more likely to encounter a sit back failure at the lift off step (step 1 in Figure 2.1 (b)) or a step forward failure at later steps (step 2-4 in Figure 2.1 (b)). The reason for these failures could be lower body weakness, balance control and coordination impairment, or both (Riley, Krebs, and Popat, 1997). So older adults who were unable to rise without using hands needed to use their arms and armrests to stabilize themselves when they lifted off the seat. Additionally, by putting their hands on the armrests, older adults who were unable to rise without using their hands also compensated their lower body weakness by using larger force from their upper body to generate enough momentum for rising successfully (Alexander, 1991).

Existing Grab Bars + Grab Bar Configurations

Toilet grab bars that are available on the market (Please see Appendix A for more existing grab bars and detailed product information) have various styles. Unlike the ADA grab bar requirements, which specify grab bars that are fixed on the wall, installed horizontally, and have specified lengths, some existing grab bars are movable, foldable, removable, rotatable, and come in a variety of sizes and shapes, which provides more flexibility to use. They are designed be mounted to the wall as well as to the floor or the ceiling. Although there was no study specifically looking at each of these off-the-shelf products, there were some studies that looked at some characteristics of the grab bars and how these characteristic impacted the way users sat down and stood up from the toilet. Based on my analysis of existing grab bars, there are four basic functional characteristics that impact use and usability. These include: location, position, orientation, profile of the cross section.

Location

Location refers to the placement of grab bars relative to the toilet, i.e. adjacent or to the side, in front of or behind. This may be different from where grab bars are installed. For example, some grab bars are mounted to the rear wall, but they provide support on the sides of the toilet (Figure 2.5, Figure 2.6, and Figure 2.7).

Figure 2.5 Elcoma Flip Up Grab Bars

Figure 2.6 Adjustable Gated Foldaway Support Rail

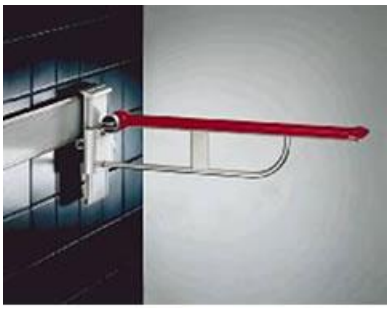


Figure 2.7 Pressalit Support Bar (Folding grab bar that can be moved horizontally)

Side of Toilet

Most existing grab bars were designed to provide support from the side of toilet (Figure 2.5 - 2.11). Grab bars on both sides of the toilet have been found to have a higher frequency of use by than those only on one side (Sanford, Echt and Malassigne, 1999). O'Meara and Smith (2006) suggested that a grab bar on one side may be effective for individuals with asymmetric impairments, and it should be placed on the side opposite to the impaired side of the body. However, when grab bars are used by a number of people, it would be more likely that they need support on both sides of the toilet, since different individuals are likely to have impairments in different parts of their bodies. As a result, grab bars installed on both sides would be used by a greater number of individuals than grab bars placed on only one side of the toilet.

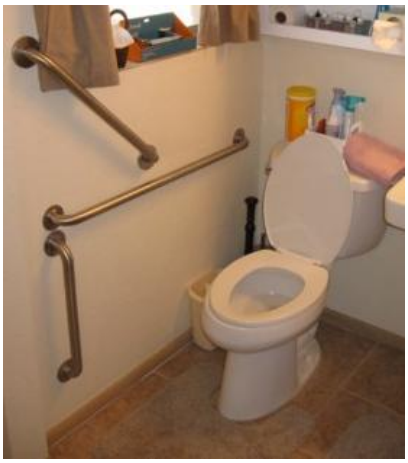


Figure 2.8 Grab bar configuration with diagonal, horizontal and vertical grab bars

Figure 2.9 Grab bar that integrates both horizontal and vertical orientations

Figure 2.10 Elite Floor Mounted Folding Support Rail

Figure 2.11 Ringwood Wall-to-floor Grab Rail

Front of Toilet

There are some vertical grab bars such as the super pole that extends from floor to ceiling. As a result, they can be installed wherever they are needed, usually to the front left or front right of the toilet. When a super pole comes with a horizontal bar (Figure 2.12) that can be rotated, it can also provide support from the front of the toilet. Unfortunately, there has been no study on how this front handle worked for people to get on and off the toilet and get in and out of the wheelchair.

Figure 2.12 Super pole with super bar

There was a study in which a horizontal grab bar located in front of the toilet (O'Meara and Smith, 2005). This study showed that a bar in front was more effective than grab bars on the side of the toilet in reducing the load in subjects' body and the time they spent to stand up (Figure 2.13). This horizontal grab bar was mounted on a wall in front of the seat in their testing. When people gripped a front bar to pull themselves up from a wheelchair (Figure 2.14 (b)), they could keep the distance between their hands the same as their shoulder width, which would allow them to use their arms rather than shoulders, compared to people who pulled themselves up using grab bars on the side of the toilet (Figure 2.14 (a)).

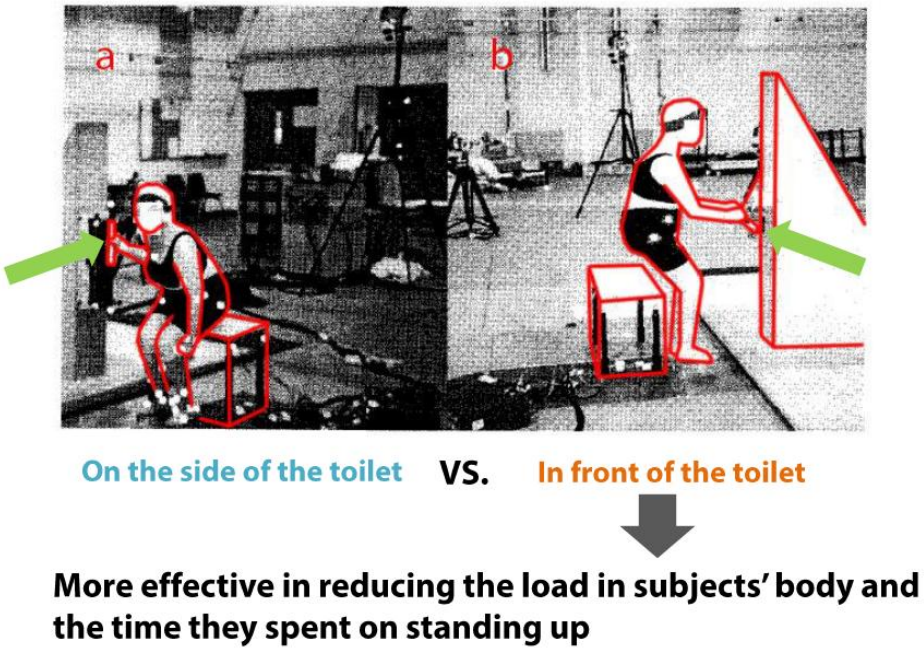


Figure 2.13 Test setting by O'Meara and Smith (2005)

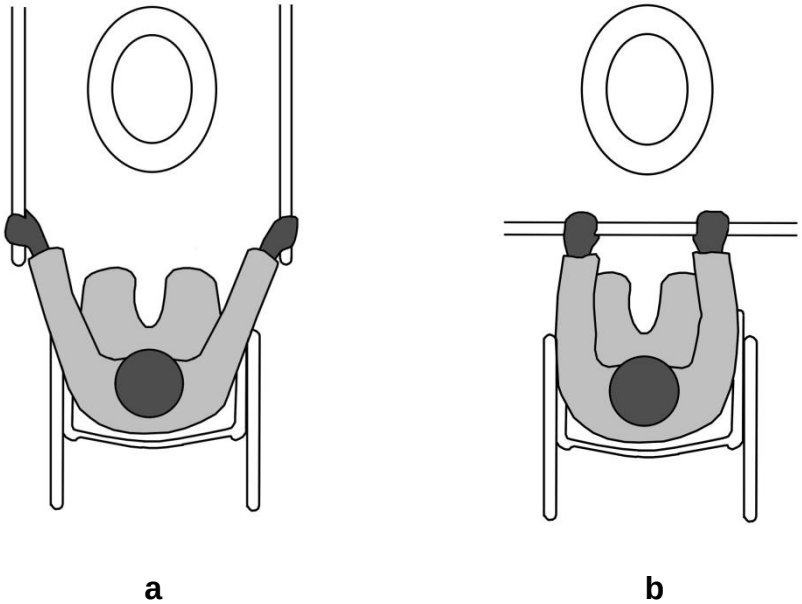


Figure 2.14

Rear of Toilet

The ADA grab bar configuration for non-ambulatory individuals has a horizontal bar on the rear wall (Figure 1.1 and 1.2). People sitting in the wheelchair who transfer from the side of the toilet may use this rear bar to pull themselves from the wheelchair to the toilet. However, older adults who transfer to the toilet from a standing position commonly transferred from the front of the toilet (Sanford, Echt and Malassigne, 1999), which resulted in the rear bar being seldom used by these people.

Position

Position refers to actual placement of the grab bars as measured by the distances between the grab bars and the toilet, floor, wall or other obstruction. Many grab bars are fixed in the position in which they are installed, however some grab bars allow the user to adjust the position of grab bars according to their needs before or in the process of transfer. Figure 2.7 shows a folding grab bar that can be moved along a horizontal track. Figure 2.10 shows a horizontal grab bar that can be moved along a vertical track. The suction cup grab bar (Figure 2.15) can be removed and placed in any position. In Figure 2.16, the curvy bar is rotatable around the vertical bar, similar to the super pole and super bar (Figure 2.12).

Figure 2.15 Suction bar

Figure 2.16 Security Pole and Curve Grab Bar

Although, there were no studies suggesting an appropriate position of grab bars, some researchers suggested that grab bars on the side should be positioned closer to the toilet for independent transfer. Koncelik (2002) mentioned that the grab bars on the side of the toilet should be closer to the toilet to facilitate the pushing strength from the folded arm rather than the weaker pulling strength from the extended arm. In the FRR (Friendly Rest Room) project (FRR, 2002-2005), researchers tested a toilet prototype on a group of subjects with mobility impairments. Their prototype used two folding grab bars on left and right side of the toilet. Although the main focus of FRR project was the toilet height adjustment and tilting angle, subjects also reported that the distance between the grab bars should be adjustable for different people.

Other studies examined the effects of handrail height on sit-to-stand movement. Researchers from Sweden (Wretenberg, Lindberg, and Arborelius, 1993) suggested that people with great difficulties in rising should use high armrests. The armrests they used in their testing were actually two handrails. They set the handrails at three different heights as shown in Figure 2.17. The subjects in their testing were all healthy young males who did not have difficulties standing up from a chair. So for older adults who were unable to stand without using armersts, the impact of armrest height and hand placement on the sit-to-stand process may be different.

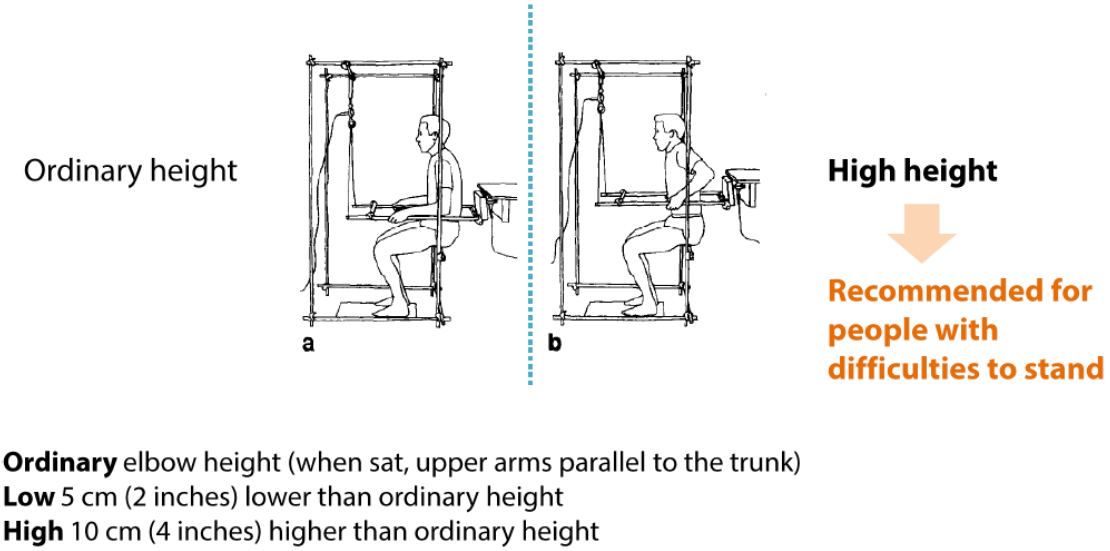


Figure 2.17 Test setting by Wretenberg, Lindberg, and Arborelius (1993)

Another study (Kinoshita, 2012) compared three groups of subjects (college students, independent elderly people and physically challenged elderly people) using pairs of handrails to stand up from a chair. Five types of handrail positions (no handrails, both high, both low, high (left) and low (right), low (left) and high (right) (to see the effects of dominant hands)) were evaluated (Figure 2.18). The researchers found that sit-to-stand movement using high and low (or low and high) handrails took elderly subjects the shortest time to stand up and showed the largest decrease in torque compared to no handrails. Kinoshita (2012) also found that persons who placed an arm on the handrail and used it to stand up tended to lean their trunk far forward from the hip joint, with a particularly large angle of hip joint flexion. For this reason the researcher suggested that it was important that the low handrail had a sufficient width and sufficient low height to facilitate placement of body weight through arms on the handrail.

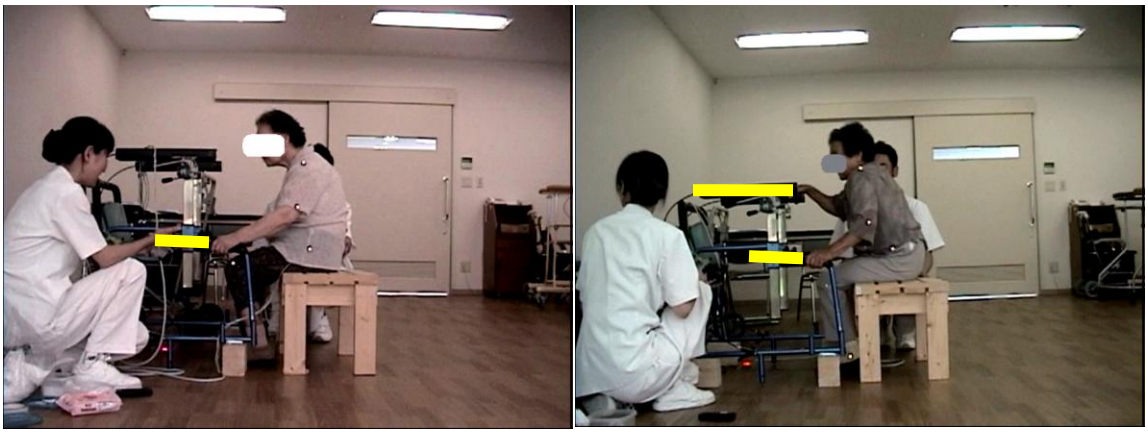


Figure 2.18 Test setting using "both low" and "high and low" handrails (Kinoshita, 2012)

Munton, Ellis, Chamberlain and Wright (1981) recommended that chair armrests should protrude from the front edge of the seat to ensure that older adults have contact with chair when they lift off from the chair. Similarly, the ADA grab bars (Figure 1.4) are required to be extended at least 54 inches from the rear wall of the toilet.

When a grab bar extends too far forward from the toilet and beyond the seated reach range of the people, it is possible that their hands will move backward along the grab bar (Figure 2.19) if there is no enough friction between their hands and the surface of the grab bars, based on a study about the effect of handrail shape on graspability (Dusenberry, Simpson, DelloRusso (2009)). In contrast, Figure 2.7 and Figure 2.10 are two examples of grab bar position that people could grip without their hands moving backward.

Grab bar that extends beyond the seated reach with enough friction to grab along its length

Grab bar that ends within seated reach Can be grabbed on the end

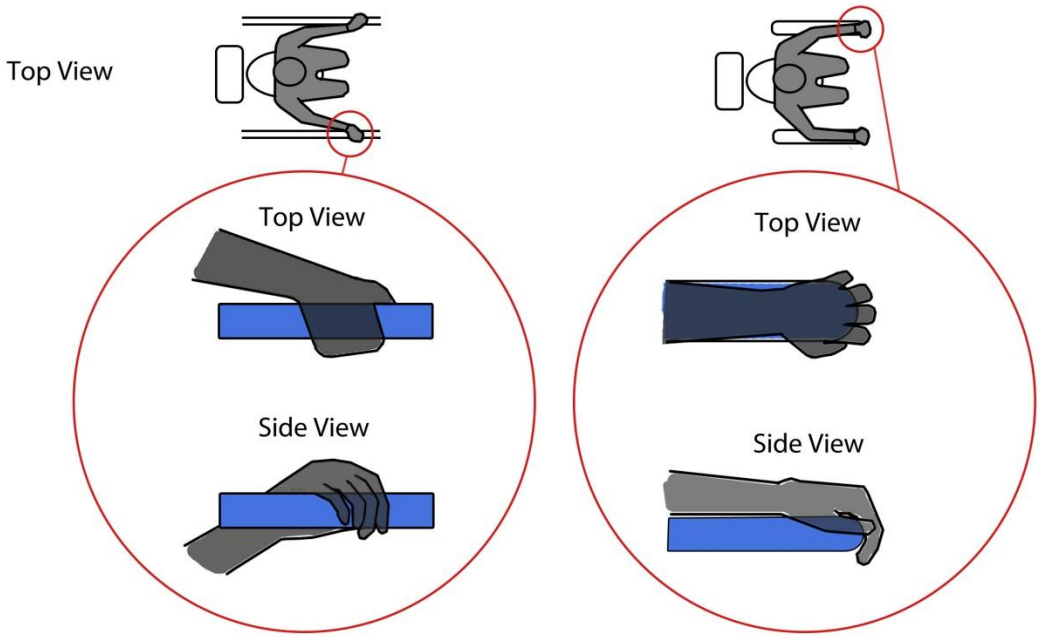


Figure 2.19

Orientation

Orientation refers to the direction of the longitudinal axis of an installed grab bar. There are three main orientations: horizontal (parallel to the floor), vertical (perpendicular to the floor) and angled (between 0 and 90 degree relative to the floor) (Seton and Bridge, 2006). Horizontal installations are recommended by legislative requirements in most countries (e.g. ADAAG) and suggested by all manufacturer specifications (Seton and Bridge, 2006).

Generally, horizontal orientation helps people with lower body weaknesses; vertical orientation helps people with upper body weaknesses (Seton and Bridge, 2006). However, wall mounted stationary horizontal grab bars have been shown to be less effective transfer compared to other orientations in providing assistance during the sit-to-stand (Maben, 2003; O'Meara, 2003), where moving the hand up vertical or angled bars can increase transfer independency in all stages of the transfer (Maben, 2003).

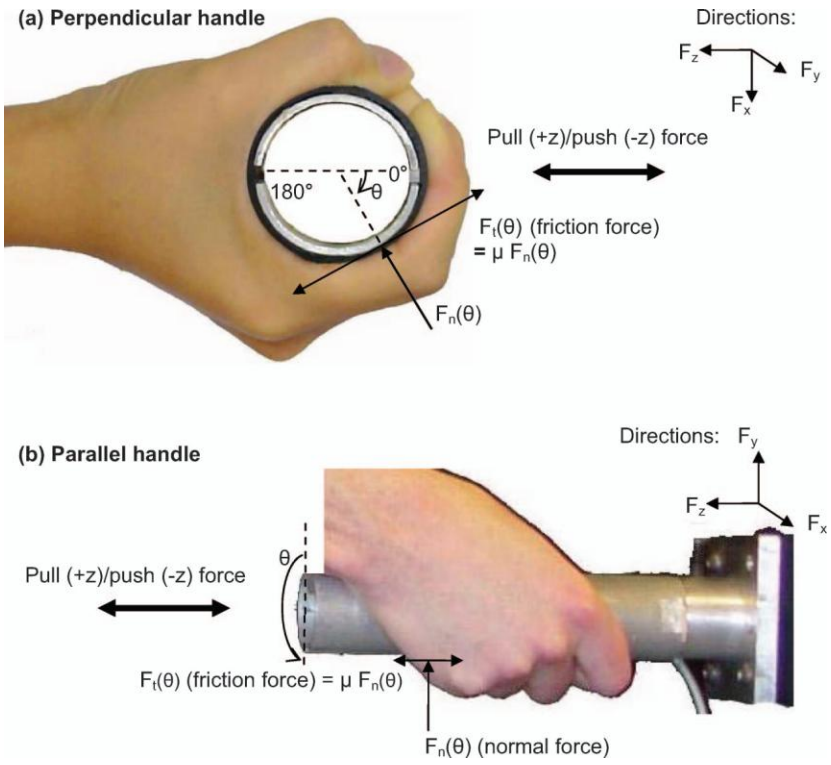


Figure 2.20 (Na Jin Seo, Thomas, Justin, 2010)

In a study focused on the effects of handle orientation, Na Jin Seo, Thomas and Justin (2010) showed that a handle oriented at a right angle to the forearm (such as a grab bar located in front of the toilet, Figure 2.13 (b)) vs. a handle oriented parallel to the forearm (such as a grab bar located on sides of the toilet, Figure 2.13 (a)) had different effects on pull forces to the hand. The pull force on a perpendicular handle (Figure 2.20 (a)) was shown to be stronger than on a parallel handle (Figure 2.20 (b)). Thus, when people pull themselves up using grab bars located in front of the toilet, they might generate more force than using grab bars located on the side of the toilet.

Other than standard grab bars in horizontal and vertical orientation, Figure 2.8 shows an example of existing grab bars in an angled orientation. In the laboratory study by Sanford, Echt and Malassigne (1999), subjects used a grab bar configuration that had a diagonal bar on the side of the toilet (Figure 1.6). However, since it was only installed on

one side of the toilet, it was not as easy as the two folding grab bars on both sides of the toilet.

Profile

Profile refers to the size, shape and cross section of a grab bar. Most grab bars available on the market have constant profiles along its longitudinal axis, typically from 1 ¼ inches to 1 ½ inches.

Size

A study on the relationship between handle diameter and grip force showed that the comfortable handle diameter was almost about 19.7% of the user's hand length (Kong, 2005). Kong recommended that the handle diameter be 1.24 inches to 1.47 inches for 5 percentile to 95 percentile women, and 1.35 inches to 1.59 inches for 5 percentile to 95 percentile men. This was similar to 1 ¼ inches to 1 ½ inches that ADAAG requires for the diameter of a round grab bar (Figure 2.21). Because people have different grip forces and hand lengths, it is reasonable that the handle diameter might vary.

Shape

Although most grab bars are round, new designs are available with different cross-section shapes. The new ADAAG (2010) added requirements that grab bars with non-circular cross sections should have a cross-section dimension of 2 inches (51 mm) maximum and a perimeter dimension of 4 inches (100 mm) minimum and 4.8 inches (120 mm) maximum (Figure 2.22).

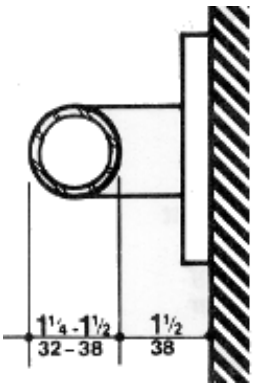


Figure 2.21 Grab Bar Circular Cross Section (Fig. 39(e) ADAAG 1991)

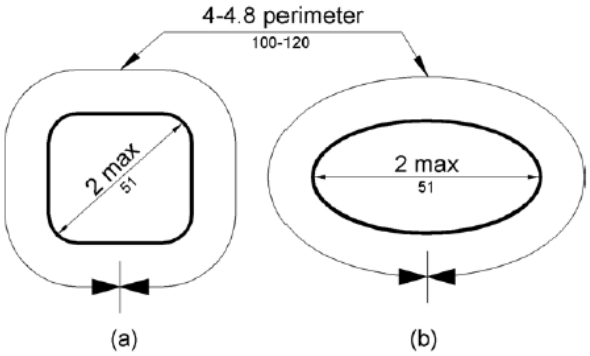


Figure 2.22 Grab Bar Non-Circular Cross Section (Figure 609.2.2 ADAAG 2010)

Although there has been little research that directly examined the profiles of grab bars, there have been studies on the profiles of stairway handrails. Dusenberry, Simpson and DelloRusso (2009) attempted to establish a relationship between the handrail cross-section and handrail effectiveness as a grasping surface for stairway use. They tested several handrail profiles with different recess depths, widths and crown heights (Figure 2.23). While the width and crown height were relatively unimportant, the recess depth was an important factor affecting handrail performance in terms of the probability of loss of grip. The round profile and profiles that had deep recess depth were likely to be better than profiles that had shallow or no finger purchase.

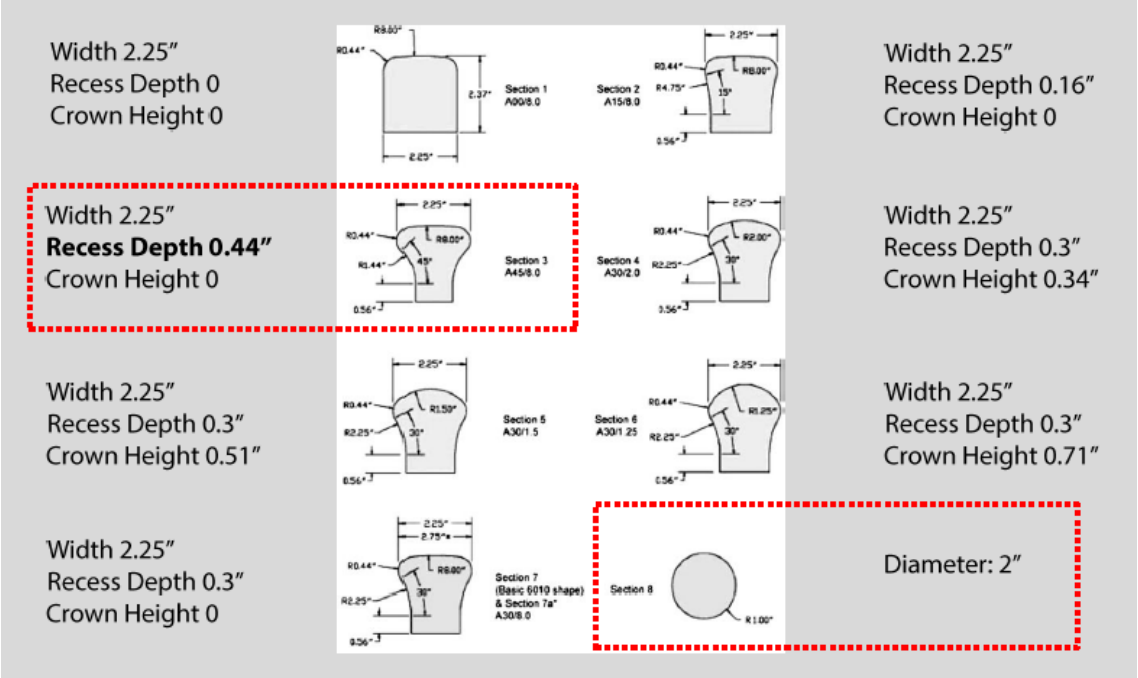


Figure 2.23 Stairway Handrail Profiles (Dusenberry, Simpson and DelloRusso, 2009)

Although the shape of grab bars look similar to stairway handrails, the findings from studies of stairway handrail profiles should not be used as a guideline for grab bar profiles because handrails are used for different purposes in different environments. Stairway handrails are installed along the stairway (inclined to floor), are used for balance in descent and pulling on ascent. The body is always moving forward as opposed to up and down and turning. Mostly a fall happens because the user loses the grip in the longitudinal direction (along the axis of the handrail) while he or she is moving up or down (Dusenberry, Simpson and DelloRusso (2009)). So it was very important to choose a handrail whose profile had less probability of loss of grip in that direction. This study suggested that the round profile of a handrail should be avoid if people will move along the handrail.

Some existing grab bar designs (Figure 2.24) have a flat top surface which is similar to chair armrests, but the width of these grab bars is still narrow. Researchers (Holden, Fernie and Lunau, 1988) recommended wider width for chair armrests for better

distribution of load on the arm. They stated that because when a person relaxed in a chair with his/her forearms resting at an inward angle of approximately 30-60 °(Figure 2.25), only a small area of the arm was in touch with the armrest. But they did not suggest specifically how wide armrests should be. They also suggested that the end material of the armrest must be firm to provide a solid platform for support and pushing off from the chair.

Figure 2.24 Folding Support System

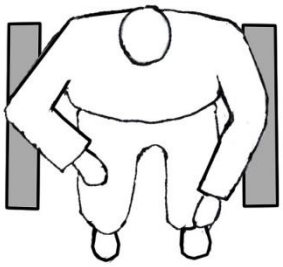


Figure 2.25

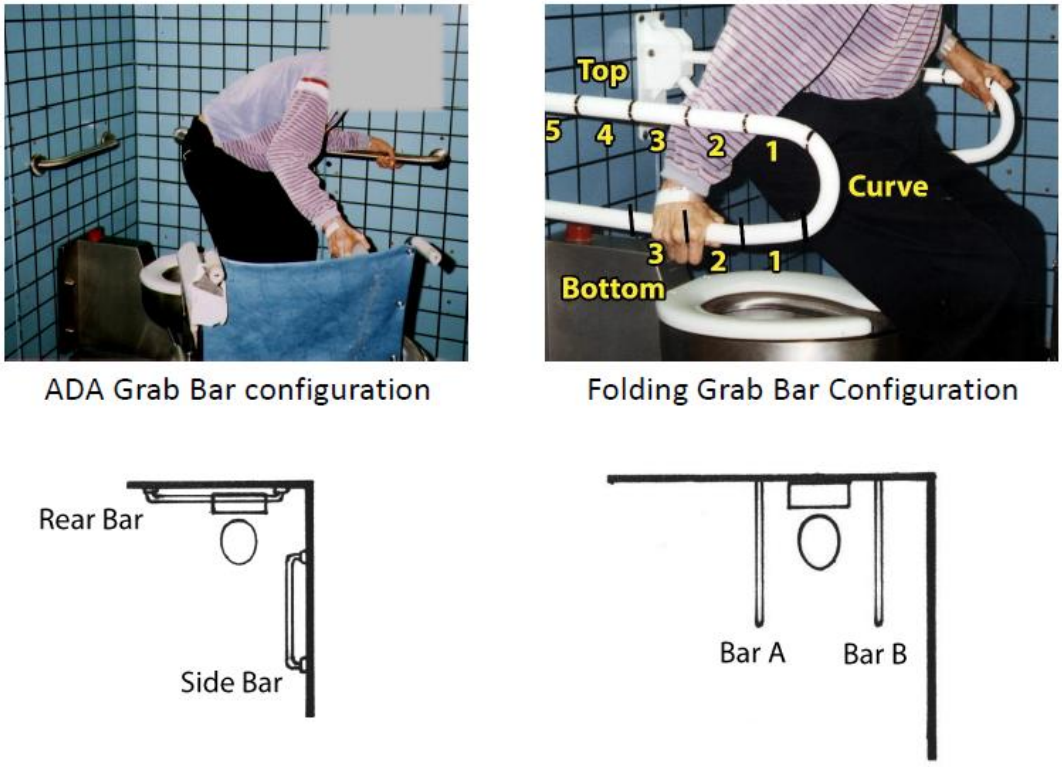
Previous Work

The video record of toilet transfers collected in the 1990s for the project comparing ADA and alternative grab bar configurations (Sanford, 2002) was analyzed in this study to determine how people who stood to transfer used ADA and folding grab bar configurations.

Grab Bar Configuration

In the folding grab bar configuration, two grab bars were mounted to the rear wall of the toilet and placed on both sides of the toilet. The grab bars in this configuration were manufactured by Linido (See Appendix A for detailed information of this grab bar). Each grab bar was divided into 6-inches segments as shown in Figure 2.26. In addition, the bar was divided into top, bottom, and front zones. Top and bottom zones were horizontal equally distributed into segments behind the front curved zone. Bar A is the bar on the left side of the user when the user is facing the front of the toilet, and Bar B is the other bar, as shown in Figure 2.26.

In the ADA configuration (Figure 2.26), there was one long bar on the side of the toilet and one rear bar on the rear wall of the toilet. They were not marked like the folding grab bars.



ADA Grab Bar configuration

Folding Grab Bar Configuration

Figure 2.26 ADA and Folding grab bar configuration

Methods

Subjects

People who didn't stand to transfer onto the toilet and people who didn't use wheelchairs were excluded. Thirty-seven subjects (32 Male, 5 Female) used the folding grab bars. Among those, 29 subjects (26 Male, 3 Female) also used the ADA grab bar configuration for comparison. All subjects transferred from the front of the toilet in the folding configuration (Figure 2.26).

Coding transfers

Each transfer was coded according to the six sequential steps defined by me in the transfer process (See Figure 2.27 for illustrations of the transfer process):

- Sit to stand from wheelchair facing toilet

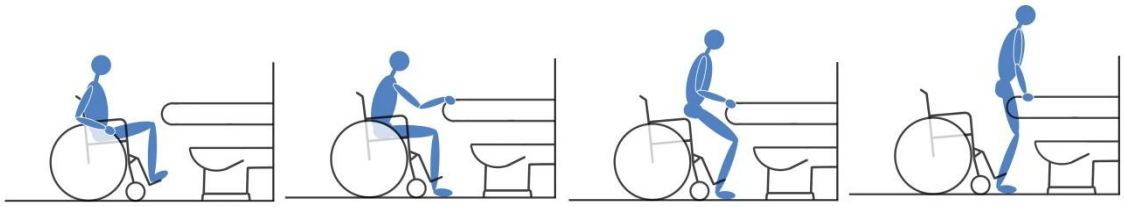
- Pivoting to face away from toilet
- Stand to sit onto toilet seat
- Sit to stand from the toilet
- Pivoting to face toilet
- Stand to sit into wheelchair

Each zone of the folding grab bars was coded according to the location of the user's hands. A rating of 1 was assigned to a segment if the user's hand was entirely within that segment. A rating of 0.5 was assigned if the user's hand was partial within a segment. A rating of 0 was assigned if the user's hand was not placed within a segment at all during the transfer sequence.

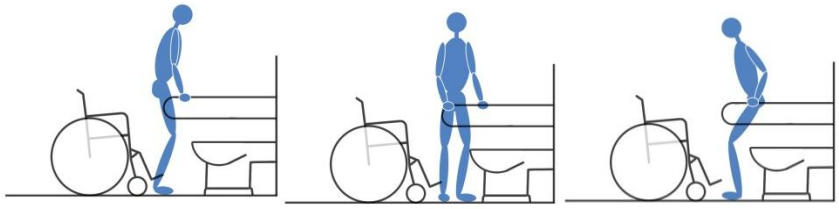
Use of the side bar and the rear bar in the ADA configuration were similarly rated 0 or 1 according to whether the user's hands were located on it during the transfer process. A rating of 1 was assigned if the user's hand was put on the bar. A rating of 0 was assigned if the bar was not used at all.

Use of wheelchair armrests during the transfer process was also scored according to whether the user's hands were located on them. A rating of 1 was assigned if the user's hand was put on the armrest. A rating of 0 was assigned if the armrest was not used at all.

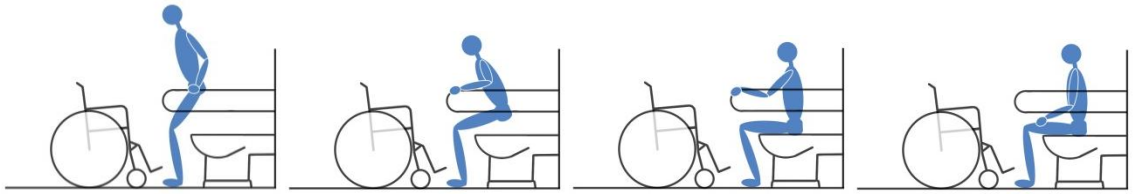
Sit-to-stand from wheelchair



Pivoting to face away from toilet



Stand-to-sit onto toilet seat



Sit-to-stand from the toilet

Pivoting to face toilet

Stand-to-sit into wheelchair

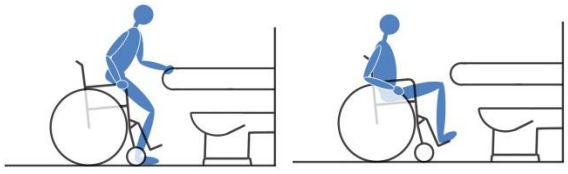


Figure 2.27 Six Steps in Transfer Process

Results

Use of folding grab bars

The folding bars were used 302 times by 37 subjects (Table 2.1). The top zone was used 250.5 times. It was used throughout each stage of transfer process except getting on the wheelchair (17.5 out of 250.5 times). However, the top part was used more often for pivoting and sitting down than for any other tasks (62 and 56 times respectively).

The bottom part and the curved part of the folding bars were used much less frequently (30 and 21.5 times, respectively) than the top part (250.5 times). The bottom part was used primarily when people sat down on the toilet (15 out of 30 times) and got up from the toilet (10 out of 30 times). The curved part was used primarily when people got up from the toilet (10.5 out of 21.5).

In terms of each segment of the top zone, Top1 was the most frequently used segment accounting for nearly half of the uses (149 out of 302 times). Top 1, 2 and 3, which were closest to the point of transfer, were used 238.5 times, which was nearly 4/5 of the total usage.

Table 2.1 Use of Folding Configuration

Process		Top					Curve	Bottom			Wheelchair
		T5	**T4**	**T3**	**T2**	**T1**		**B1**	**B2**	**B3**	
Getting on the toilet	Sit to stand from wheelchair facing toilet	1	0	22	5	23.5	3.5	1	0	0	28
	Pivoting to face away from toilet	0	3	10	14	28	1	0	1	0	11
	Stand to sit onto toilet seat	0	3	4	15	29	4	5	8	2	4
Getting off the toilet	Sit to stand from the toilet	0	2.5	3	8.5	31.5	10.5	2	3	6	5
	Pivoting to face toilet	1	1.5	8.5	7.5	21.5	1	2	0	0	31
	Stand to sit into wheelchair	0	0	0	2	15.5	1.5	0	0	0	36
Whole process		2	10	37.5	**90**	**149**	21.5	10	12	8	115
Sum		**250.5**					21.5	30			**115**

*37 (32 Male, 5 Female) subjects used folding configurations.

The two bars (A and B) on both sides of the toilet were equally used (151:151) in the whole process (See Table B.2 in Appendix B). In each step, the frequency of use of each bar was slightly different, but fairly equal.

Use of ADA grab bars

The two bars in ADA configuration were used 129 times by 29 subjects (Table 2.2). The rear bar was seldom used (5 times) because it was difficult to reach. All uses of the rear bar were when people got on to the toilet. The side bar was used less often when people got in and out of the wheelchair (12 and 11 times respectively).

Table 2.2*: Comparison between ADA and Folding Configuration

process		ADA Configuration			Folding Configuration		
		Grab Bar		Wheelchair	Grab Bar		Wheelchair
		Side Bar	Rear Bar		A	B	
Getting ON the toilet	Sit to stand from wheelchair facing toilet	12	1	24	16	13	22
	Pivoting to face away from toilet	25	2	8	22	26	10
	Stand to sit onto toilet seat	27	2	8	25	27	4
Getting OFF the toilet	Sit to stand from the toilet	27	0	13	24	26	4
	Pivoting to face toilet	22	0	18	22	12	24
	Stand to sit into wheelchair	11	0	24	6	9	26
Sum		124	5	95	115	113	90
Total		129		95	228		90

*29 (26 Male, 3 Female) subjects use both ADA and folding configurations.

Use of the wheelchair

In the folding grab bar configuration, the wheelchair was used primarily while people were getting out of it (28 times), pivoting themselves after toileting (31 times), and getting on to it (36 times). In the ADA configuration, the wheelchair was used more often than the grab bar when people got out of the wheelchair (24: 13), and got on to the wheelchair (24:11). The grab bars were used more often than the wheelchair when people pivoted themselves (27: 8) and then sat down on the toilet (29: 8). The use of wheelchair increased from 8 to 13 times when people stood up from the toilet and increased to 18 times when people pivoted.

Overall, the use of wheelchair in both configurations was about the same (95 and 90 times respectively) (Table 2.2). However, the ratio of grab bar to wheelchair use was significantly higher with the folding configuration (2.53) than with the ADA configuration (1.36).

Analysis of Grab Bar Use during Transfer Process

Folding Configuration

People of different heights used different parts of the folding grab bars for transferring. For example, short female subjects used the bottom part of the folding grab bar for pushing when they started to get up from the toilet, and they also moved their hands to the top part as they stood up. In contrast, taller male subjects often stood up from the toilet by putting their hands on the top part of the folding grab bars (Figure 2.28). Nonetheless, some subjects who may have asymmetric physical abilities used both top and bottom part of the folding grab bars to stand up from the toilet (Figure 2.29).

Figure 2.38 shows how subjects pivoted themselves from facing the toilet to facing away from the toilet. It was noticeable that because the folding grabs extended more forward than the toilet, so subjects was able to hold on the folding grabs on either side while they were pivoting themselves. And it was very important to see that the folding grabs were not too close to the toilet, so subjects were able to put their hands on the grab bars to change their postures.

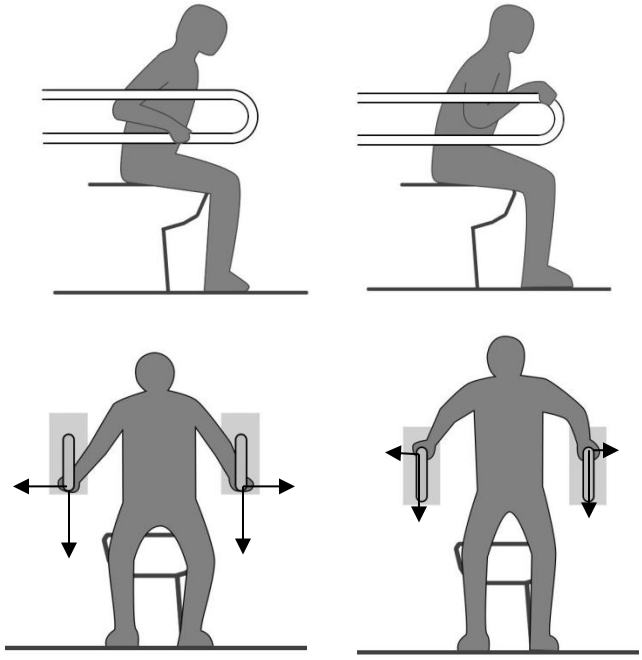


Figure 2.28

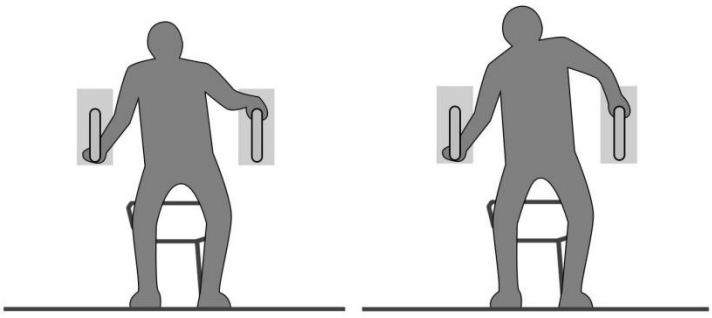


Figure 2.29

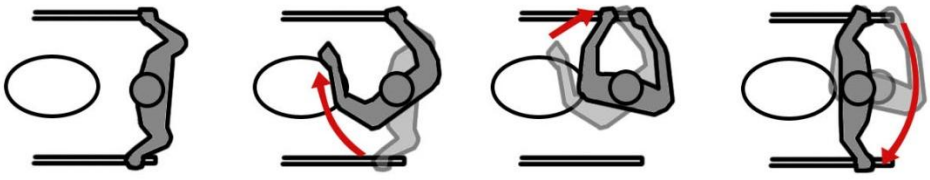


Figure 2.30 Subjects pivoted themselves using folding grab bars

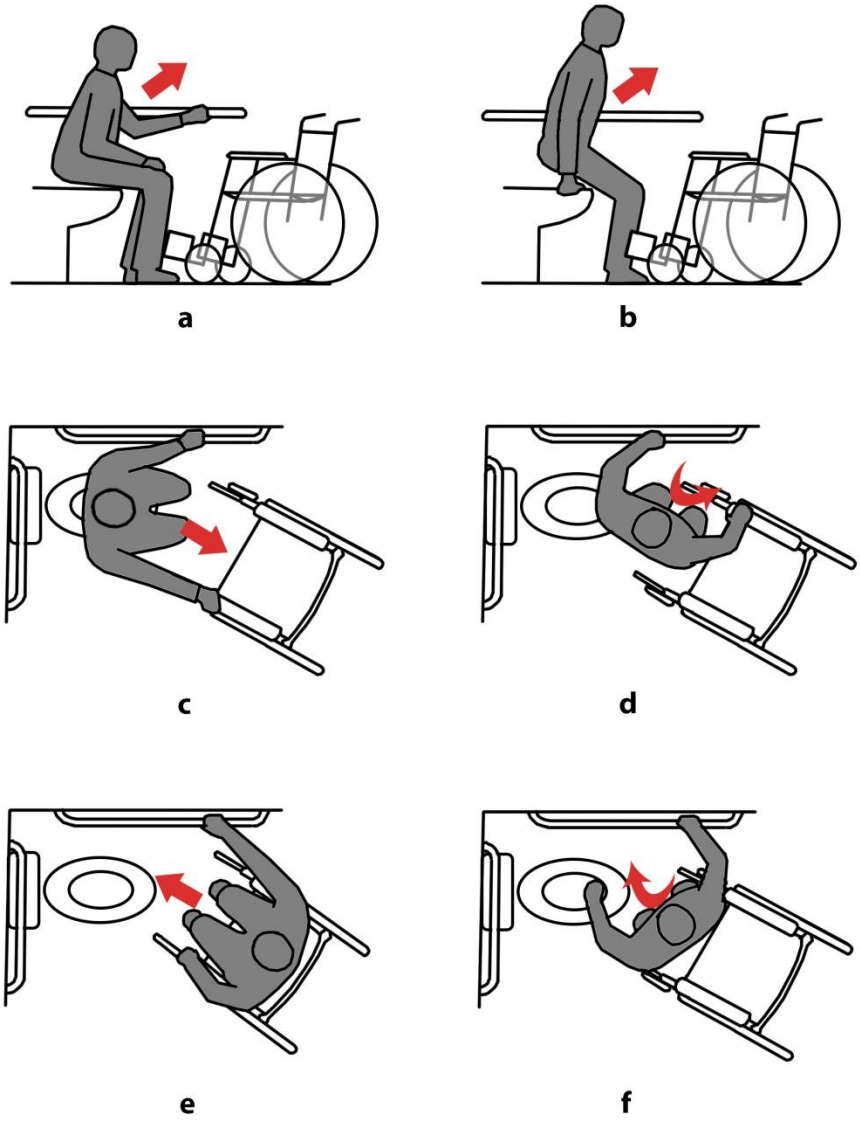


Figure 2.31 Subjects used ADA grab bars

ADA configuration

Most subjects used the side bar in ADA configuration when they stood up from the toilet. In this testing, the side bar was located on the left side of toilet when subjects faced away from the toilet. Some subject only held onto the side bar when they stood up from the toilet (Figure 2.31 (a)), others held on both the side bar and the wheelchair to pull themselves up (Figure 2.31 (c)). There were two subjects who were unable to use the

side bar because they did not have left hand or left arm. One subject pushed his hand against the edge of the toilet rather than the grab bar or the wheelchair to get up from the toilet (Figure 2.31 (b)). Subjects mostly used their right arm to pull from the ADA grab bar and used their left arm to push on the wheelchair armrest when they got out of the wheelchair (Figure 2.31 (e)). The grab bar on the rear wall provided little help to the subjects. Several subjects extended their left arm trying to reach the rear bar when they needed to pivot themselves before sat down on the toilet, but since the rear bar was located too far away, they could only hold on the side bar with the right arm (Figure 2.31 (f)).

Discussion

Use of grab bars

In the original laboratory testing, there was no mark on the ADA configuration to classify different segments on the side bar and the rear bar in this configuration. But it was noticeable from the archival video record that all subjects pulled themselves up from the toilet by gripping on the portion of the side bar that was in front of the toilet seat (Figure 2.31). They also used that portion after they stood up from the wheelchair for pivoting themselves before they sat down on the toilet.

In the folding configuration, subjects used some segments and zones more often than others because these segments and zones were located at better height and distance at that stage of transfer. For example, when subjects pulled themselves up from the wheelchair, they used the curve part of the folding grab bars because it was located the nearest to them. And when subjects stood up from the toilet, they pushed on T3 segment of the folding grab bars, and bended their trunk forward because they need to put their hands more backward than their trunk for pushing up easily. In contrast, subject pulled

from T1 segment of the folding grab bars to stand up from the toilet because they need to extend their arms as forward as possible for pulling up easily.

Use of the wheelchair

Even though grab bars were used more often than the wheelchair, the frequency of wheelchair use did not change much between the ADA configuration and the folding configuration. Both the ADA configuration and the folding configuration did not give full support for the subjects during the transfer process, especially when subjects got out of and back in the wheelchair. It is important to consider the use of wheelchair in the toilet transfer, because in an independent toilet transfer, the wheelchair may not be locked, then it is possible that when older people hold on to it in the transfer it moves and causes falls. In order to prevent this potential hazard and ensure the safety of independent toilet transfer, the design of grab bars should consider ways to reduce the use of wheelchair as much as possible.

Conclusion

The results showed that grab bars on both sides of the toilet were used more often than having them only on one side of the toilet. The folding grab bars allowed older adults to use both arms and hands and stabilize themselves in the transfer. Both high and low part of the folding grab bars were used by people in different anthropometries and physical conditions. However, the folding grab bars were too far apart that subjects were pulling or pushing from their shoulders which were typically weaker than arms, and part of the force was wasted to push the grab bars aside. Both ADA grab bars and folding grab bars did not avoid the use of wheelchair when people got out of and back in to the wheelchair, which would be potentially dangerous if the wheelchair is unlocked or moving during the transfer. The design of the new grab bar should look at ways to reduce

the efforts for sit-to-stand transfer from the toilet and the wheelchair, and to reduce the use of wheelchairs at the same time.

CHAPTER 3

DESIGN GOAL AND CRITERIA

Design Goals

Above all, I summarized the function of the new grab bar based on the literature review, analysis to the existing design and the observation of people using existing grab bars:

- Grab bars should be able to help older adults stand up from a sitting position and sit down from a standing position.
- Grab bars should be able to take the body weight of older adults while they are standing.
- Grab bars used for pulling should have features that support use of hands.
- Grab bars used for pushing should have features that allow use by hands/arms.

Design Criteria

To be more specific about the characteristics of the new grab bar, I listed the following design criteria to guide the ideation of concepts and evaluation of the prototype through the testing.

Location

- There should be grab bars located on both sides of the toilet to help people get on and off the toilet (Sanford, Echt and Malassigne, 1999).
- Grab bars should be located in front of the toilet to provide support for getting out of and back in the wheelchair (Analysis of archival observation data).
- Grab bars in front of the toilet should provide clearance for pivoting (Analysis of archival observation data).

Orientation

- A horizontal orientation should be used to take the weight of people. (Seton and Bridge, 2006)
- Grab bars used for pulling should be perpendicular to the forearm. (Na Jin Seo, Thomas, Justin, 2010)

Position

- The height of the grab bar and the distance from the grab bar to the toilet may be adjustable to accommodate users with different anthropometries (Analysis of archival observation data).
- The grab bar should extend beyond the front edge of the toilet. (Ellis, Chamberlain and Wright, 1981)

Profile

- Grab bars should have circular profile for hand gripping. (Dusenberry, Simpson and DelloRusso, 2009)
- The diameter of the circular profile should be within 1 ¼ inches to 1 ½ inches (ADAAG).
- Grab bars should have a flatter surface to support forearms wherever it is needed. (Kinoshita, 2012)

Additional Considerations

- To ensure safety and compliance with existing codes, grab bars should support at least 250 pounds (ADAAG).

CHAPTER 4

IDEATION

Ideation of the short handles

Grab bars located in front of the toilet could be used by people for pulling themselves when they get out of the wheelchair and get back in it, or when they get on and off the toilet. Based on the design criteria, the grab bar had to be perpendicular to the pulling direction. So the grab bar could be horizontal or vertical in this zone (Figure 4.1). Additionally, since people are at the standing position at the end of the sit-to-stand process, the grab bar would need to support their weight. If the grab bar is vertical, people would have to grip it tightly to generate enough friction to prevent their hands from sliding. If the grab bar is horizontal, people's hands would only slide in the appropriate direction (i.e., not vertically). For this reason, the grab bar would be safer and more effective in the horizontal rather than vertical orientation.

Horizontal grab bars in front of the toilet could be one long bar that extends from one side to the other, or two short handles that provide equal support as the long bar (Figure 4.2). As we saw in the observation study, older adults pivoted themselves in front of the toilet before they sat down onto the toilet (Figure 2.38). Therefore, horizontal grab bars in front of the toilet have to be moved out of way if they don't provide enough space to fit between them to get to the toilet.

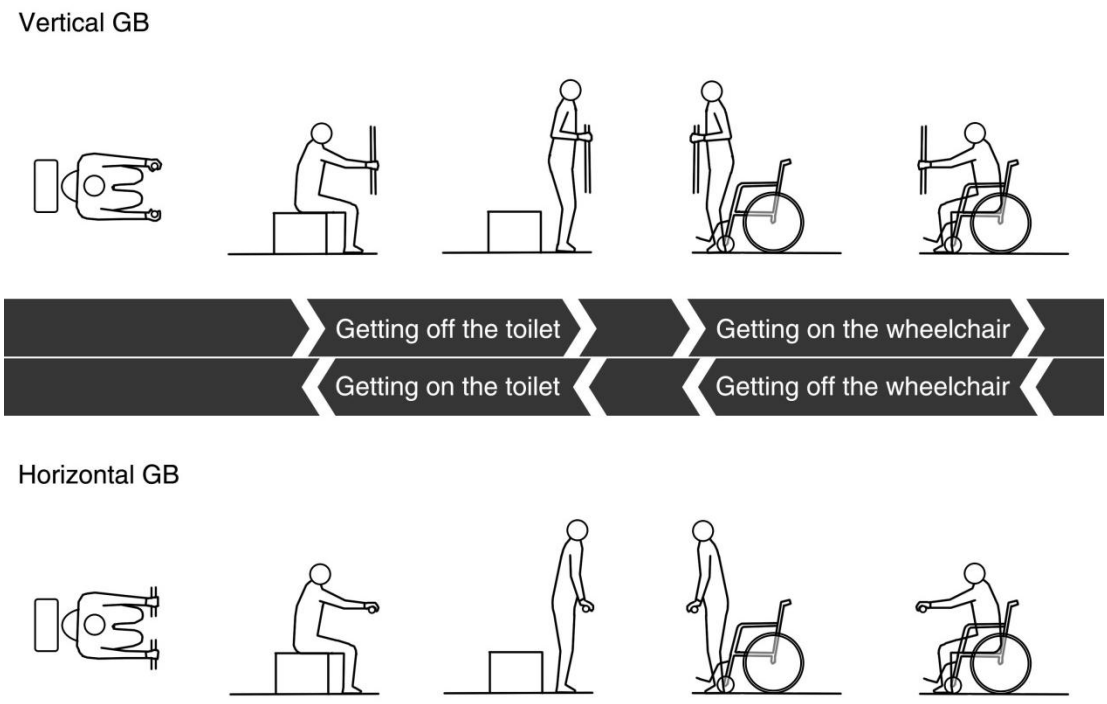


Figure 4.1

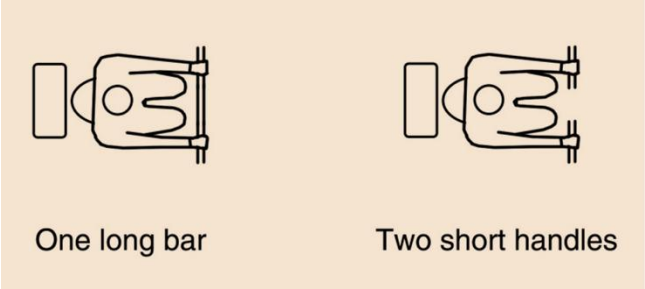


Figure 4.2

One long bar in front of the toilet

As shown in Figure 4.3 and Figure 4.4, the long bar can be rotated 90 degrees to one side of the toilet in a vertical or horizontal orientation, and it can be rotated to its original position in reverse. If the long bar can stay vertical (Figure 4.3), people will be able to hold on to it while they are pivoting, and then put the long bar back to its horizontal position before he or she can sit down on the toilet. In Figure 4.4 while people

are pushing the long bar to the side of the toilet, they pivot themselves at the same time. They may need to bend their trunk because the toilet intrudes in their transfer space (Figure 4.4 (b)). However, since people will get on and off the toilet after pivoting themselves, they can let the long bar stay on the side until they stand up from the toilet. If the toilet is further away from the long bar (Figure 4.4 (c)), people will be able to maintain a straight standing posture while they are pushing the long bar, and they can rotate the long bar back to its original position while they are sitting on the toilet. But people will still let the long bar stay on the side when they start to sit down on the toilet, because the original position will be too far for people to reach.

So it may be better to rotate the long bar to a vertical position (Figure 4.3) than a horizontal position on the side of the toilet (Figure 4.4). However, since the long bar will be on only one side of the toilet when older adults pivot and sit on the toilet, those who have limited strength and shoulder/hand conditions may have difficulty using it for getting on and off the toilet. So there should be some support on the other side to enable them use both arms to get on and off the toilet.

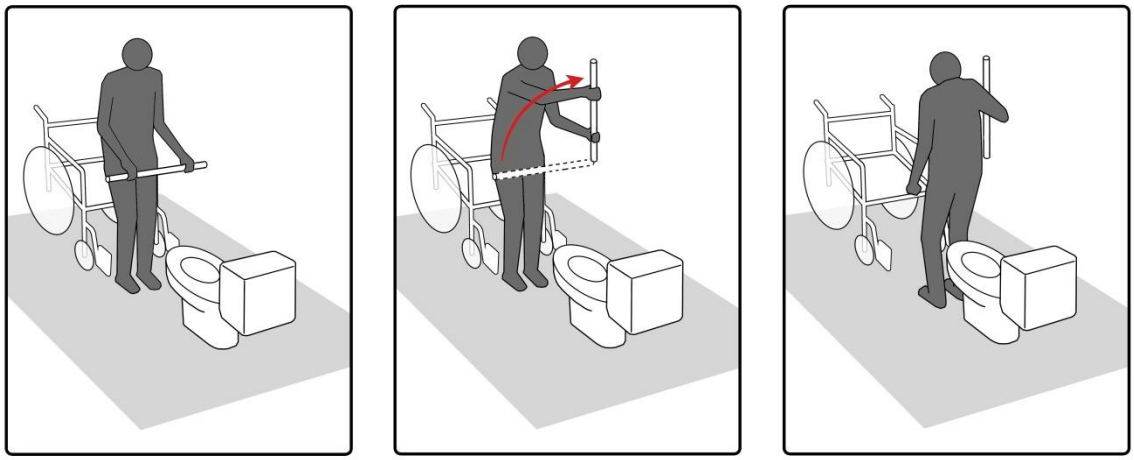


Figure 4.3 One long bar rotatable to a vertical position

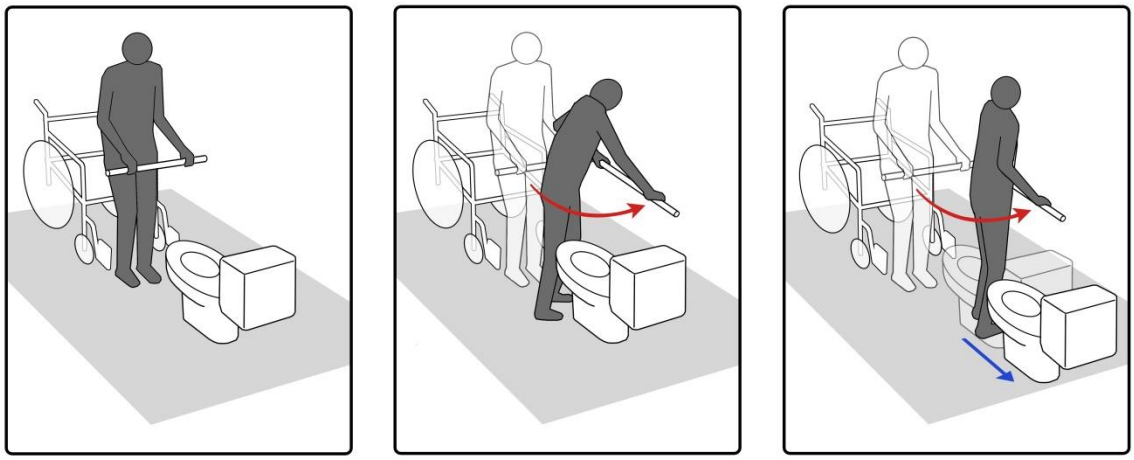


Figure 4.4 One long bar rotatable to a horizontal position

Two short handles in front of the toilet

Using two short handles solves the problem of providing support for both arms. Figure 4.5 and Figure 4.6 show two different ways to move two short handles in front of the toilet out of way for pivoting. In Figure 4.5 (a), people can grip short handles to stand up from the wheelchair. They need to push the handles around a vertical axis (Figure 4.5

(b)) in order to get access to the toilet. They can hold on the short handles while they are pivoting themselves (Figure 4.5 (c)). After that they can sit down on the toilet with the short handles on both sides of the toilet (4.5(d)) or put them back to their original positions (4.5(e)), however the latter way may interfere with people's bodies. Based on the literature review, short handles perpendicular to the arms (Figure 4.5 (e)) are easier to help people sit down and stand up than short handles on the side of the toilet (Figure 4.5 (d)). After people stand up from the toilet, they need to push the short handles away in order to get access to the wheelchair. So the short handles have to be rotated from its original position towards the wheelchair by 90 degrees (Figure 4.5 (f)). Thus, the short handles need to move to three different positions (Figure 4.5(a) (c) (f)) and be locked in its original position (Figure 4.5 (a)).

Another way to move the short handles out of way is to rotate it around a horizontal axis by 90 degrees (Figure 4.6 (a) to Figure 4.6 (b)) to its vertical position. People can hold onto them while they are pivoting themselves (Figure 4.6 (c)). Before people sit down on the toilet they can put the short handles back to the horizontal position. Thus, when people pull or push on short handles in Figure 4.6, there is no chance that the handles will move horizontally, which is much safer than the design in Figure 4.5.

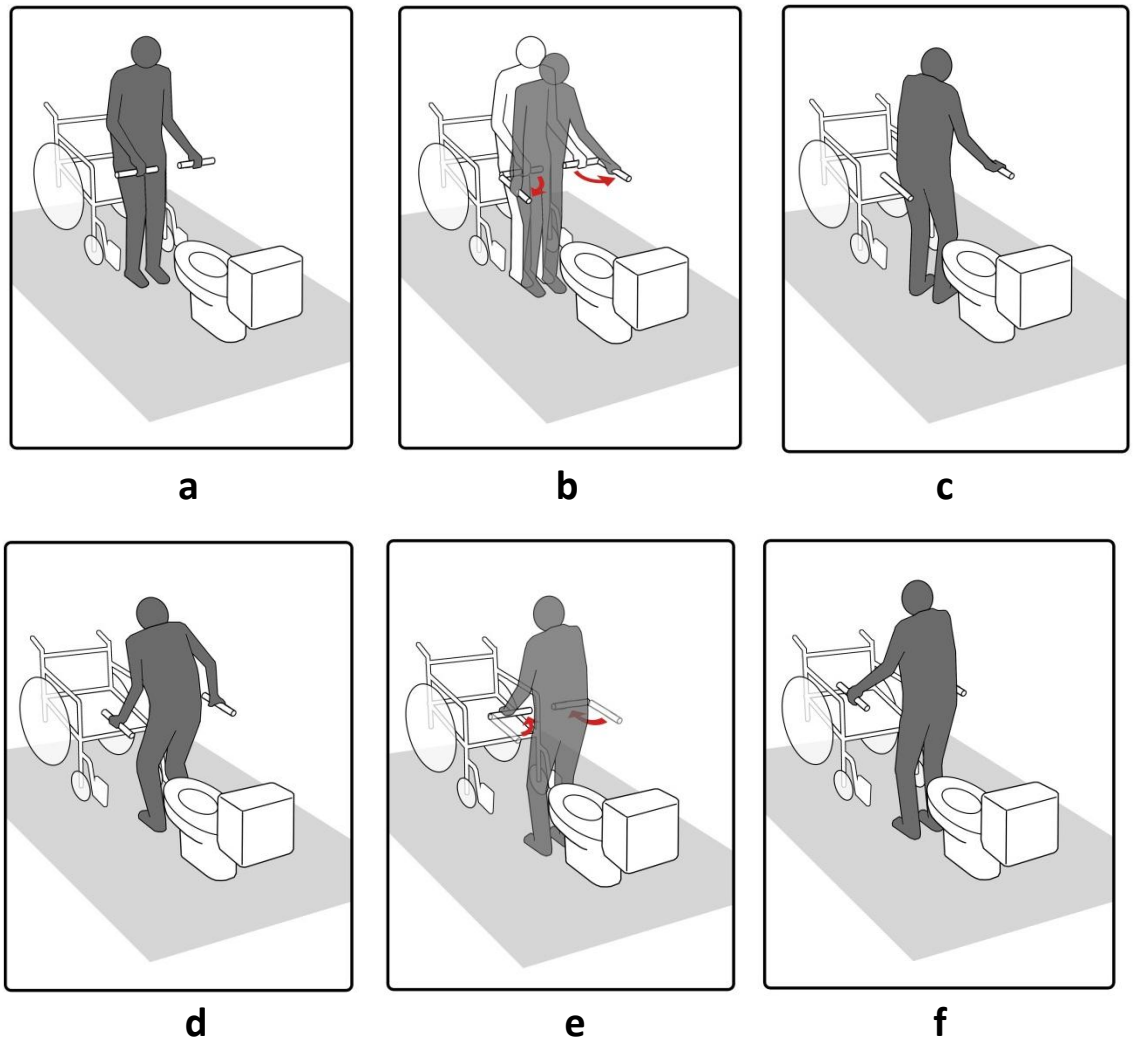


Figure 4.5 Two short handles rotatable to horizontal positions

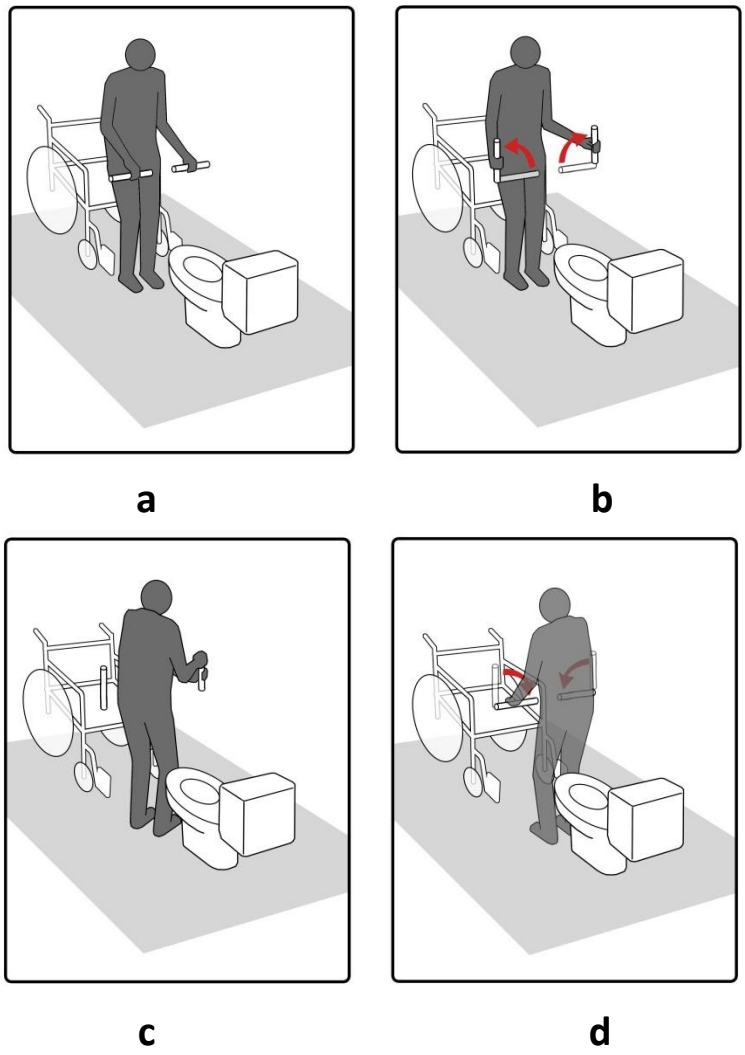


Figure 4.6 Two short handles rotatable to vertical positions

Ideation of the armrests

The idea of the armrests (Figure 4.7) was similar to existing horizontal grab bars on both sides of the toilet, but was aimed to facilitate pushing and pulling on the end of the armrest as well as make people feel less difficult and more comfortable to stand up from the toilet.

Figure 4.8 shows three ideas for the shape of the armrest end and how people would use them when lifting off from the toilet. The mouse shape fits hand better than the

flat shape and the slope shape because it follows the curve of a relaxed hand. The advantages of the slope shape is when people push against it, the forces are more concentrated.

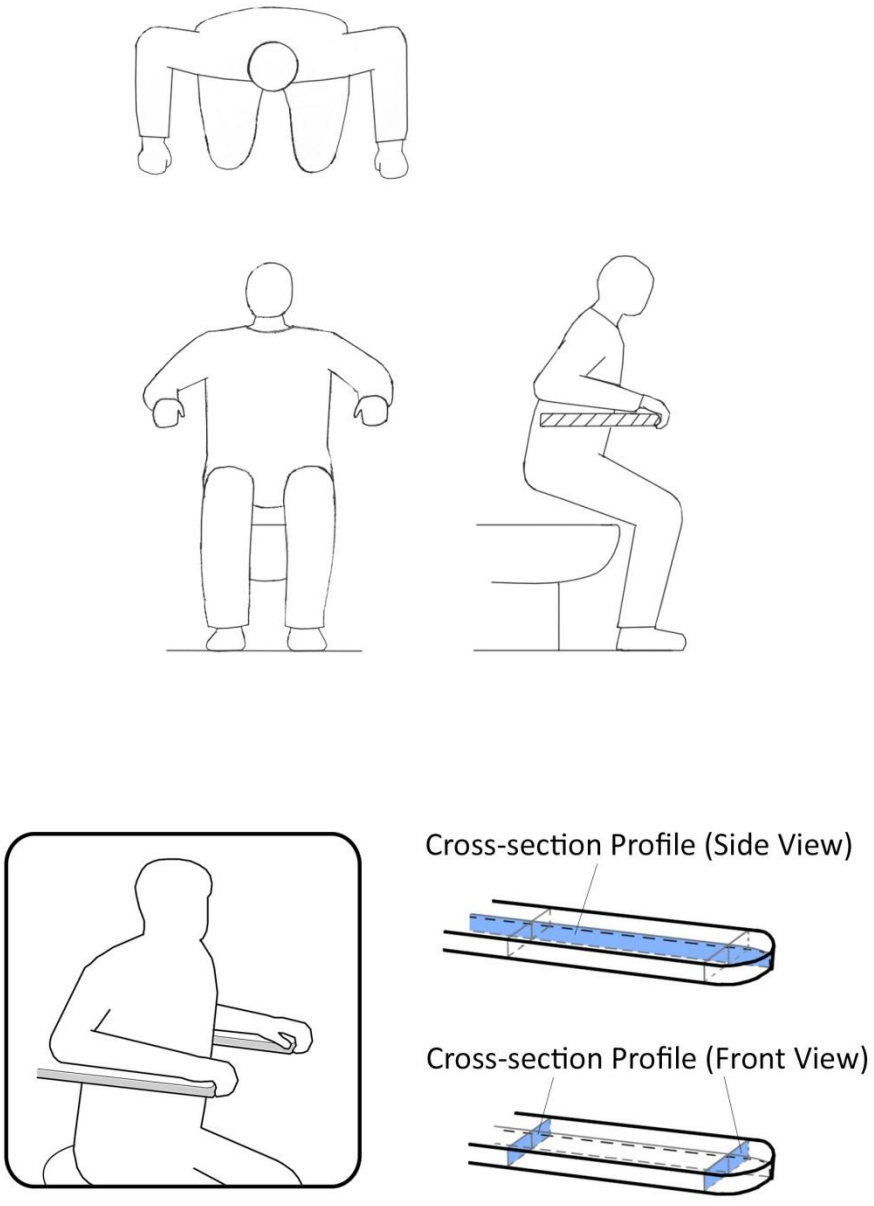


Figure 4.7

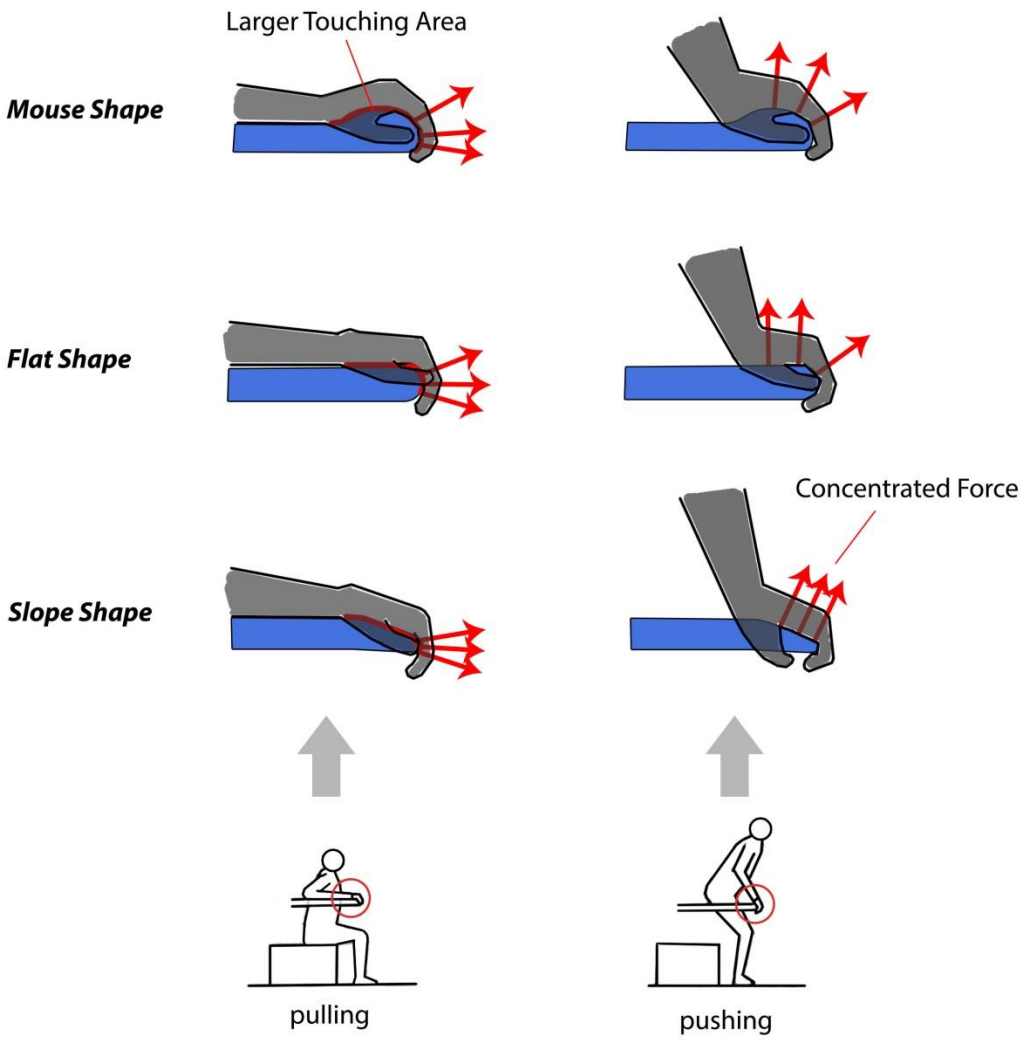


Figure 4.8 Ideas for the Shape of the Armrest End

Figure 4.9 shows two final concepts of the armrest which represented the mouse shape idea and the slope shape idea. The armrest in Figure 4.9 (a) is a slightly concaved in the middle, which is aimed to follow the curve of the forearm as well as to follow the curve of the palm. In figure 4.9 (b), the armrest has a flat top surface but bending down in the front. Both concepts were prototyped and tested later.

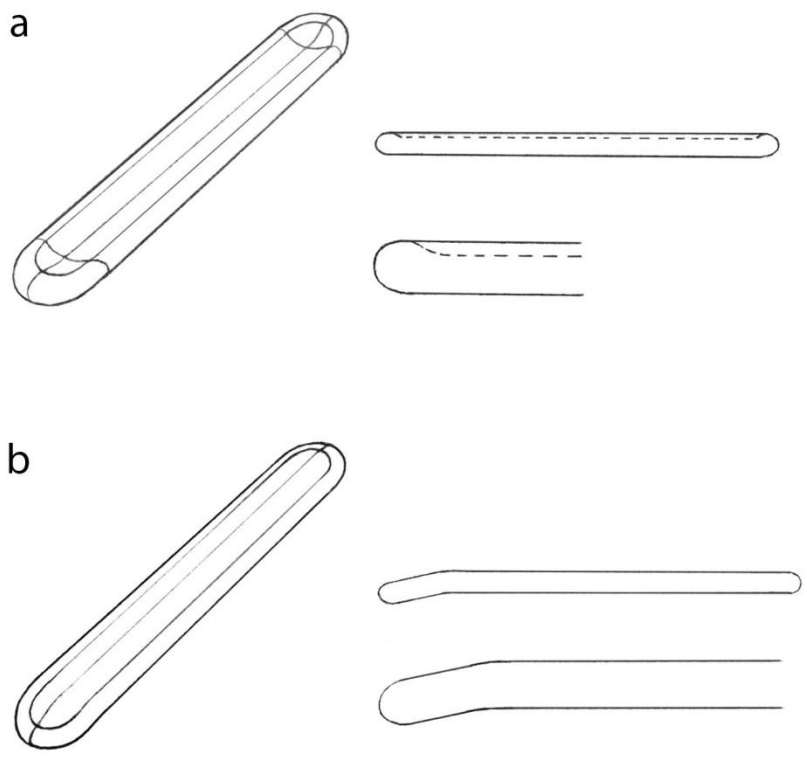
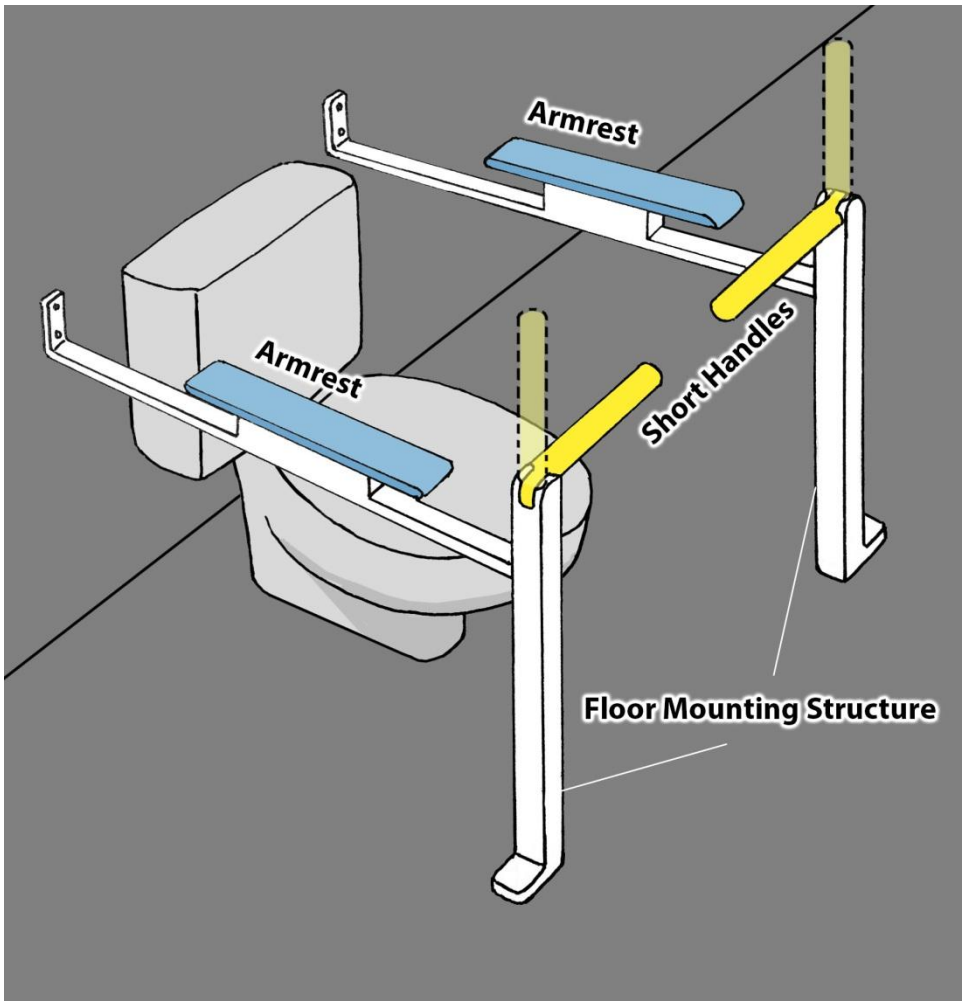


Figure 4.9 Concepts of the armrest

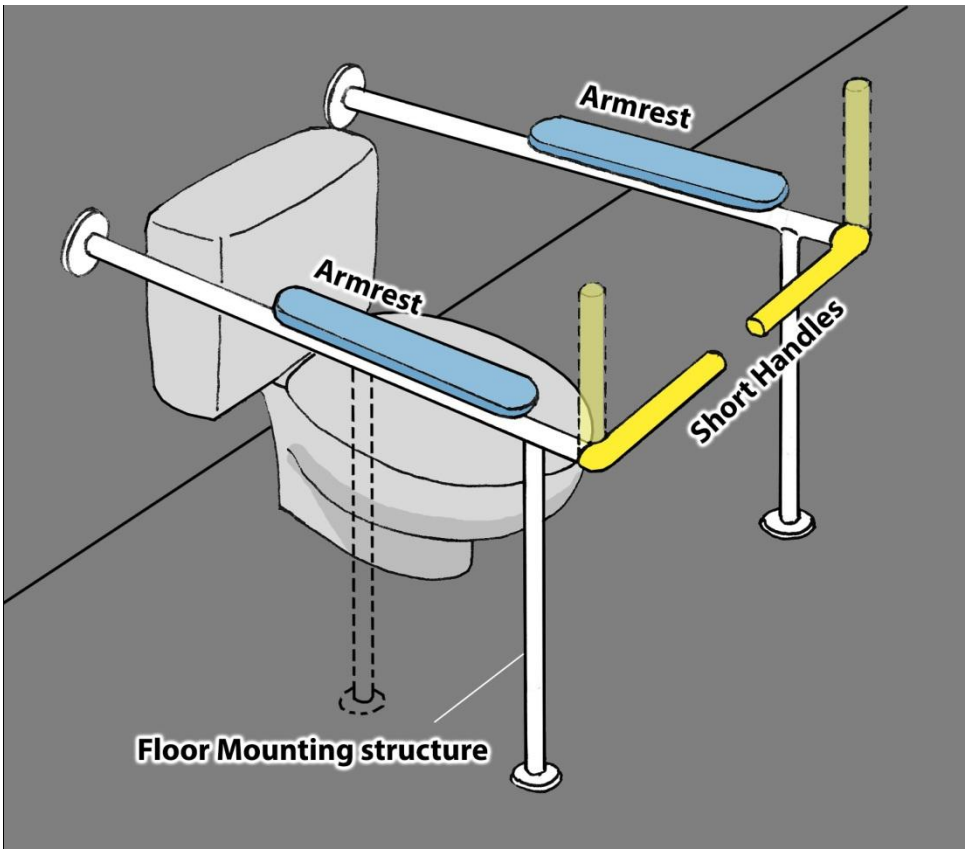
Concepts

Figure 4.10 to Figure 4.12 show three structures combining the short handles and the armrests. Both concept 1 (Figure 4.10) and concept 2 (4.11) are floor and wall mounted. The floor mounting structure may interfere with the footprint of people or the wheelchair. Although the floor mounting structure could be moved closer to the wall (the dashed line in Figure 4.11) in order to solve this problem, it is not as flexible as the structure in concept 3 (Figure 4.12) which is also foldable to the wall. For this reason, concept 3 was chosen as the concept for prototyping.



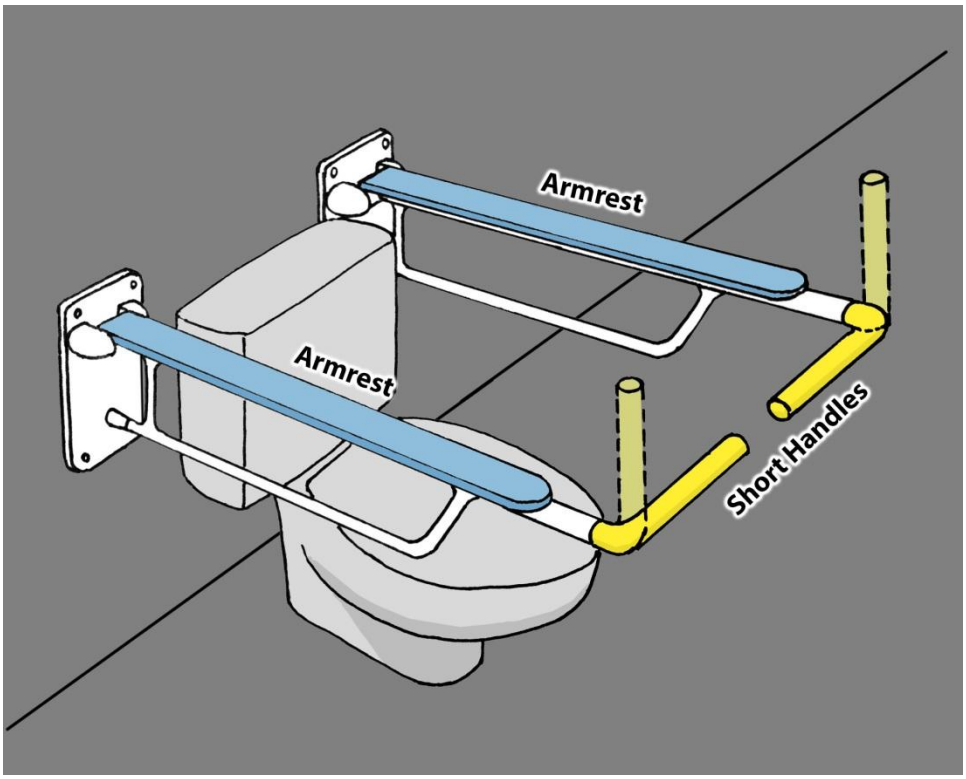
- Fixed structure, Wall and Floor Mounted
- The armrest and the short handles are at different heights, the armrests could be lower than the short handles
- The floor mounting structure will interfere with the footprint of wheelchair/people's legs

Figure 4.10 Concept 1



- Fixed structure, Wall and Floor Mounted
- The armrest is mounted closely to the side horizontal bar
- The floor mounting structure will interfere with the footprint of wheelchair/people's legs (could be moved closer to the wall)

Figure 4.11 Concept 2



- Wall mounted
- Cantilever structure, requires a lower bar and stronger material
- Do not interfere with the footprint of wheelchair/people's legs
- Foldable to the rear wall

Figure 4.12 Concept 3

CHAPTER 5

PROTOTYPING

The purpose of the prototype was to test how people would use the short handles and the armrests together or separately. In order to ensure the safety of the subjects, we decided to make the prototype as attachments to existing grab bars (Figure 5.1) which are standard off-the-shelf grab bars commonly used by older adults. They have been tested by the manufacturer and rated at 279 pounds weight capacity. They are similar to the folding grab bars in our previous observation in Chapter 2.

Folding Grab Bars by Devon (UK)
Epoxy-coated steel tube
Length 30 inches (from the wall the the front end)
Diameter 1 ¼ inches
Distance between the longitudinal axes of two bars 6.5 inches

Figure 5.1 Grab bars used in prototyping

The armrests are mounted on the top bar, with a few inches apart from the the short handles to make sure that people would be able to grab on the end of the armrest for getting up from the toilet. So the length of the armrest was restricted by the length of the grab bar. In order to allow people to grab on the end and edges of the armrest, there was 1 inch's clearance between the armrest and the top of the grab bar in the prototype. Figure 5.4 is the computer model of the short handles. Please see Appendix D for technical drawings of the short handles. Due to the machining capabilities and the budget, some changes were made to the original plan (Table 5.1).

Figure 5.2 and Figure 5.3 show the computer model of the prototype mounted to the testing frame. The short handles are mounted at the very front end of the grab bars, just before the curve part. Considering that the distance between the grab bars was adjustable, the short handles were not too long so that if the grab bars were moved closer to each other, the short handles would not hit each other. The short handles were made in the same diameter as the grab bars which was 1 ¼ inches, also complied with ADAAG.

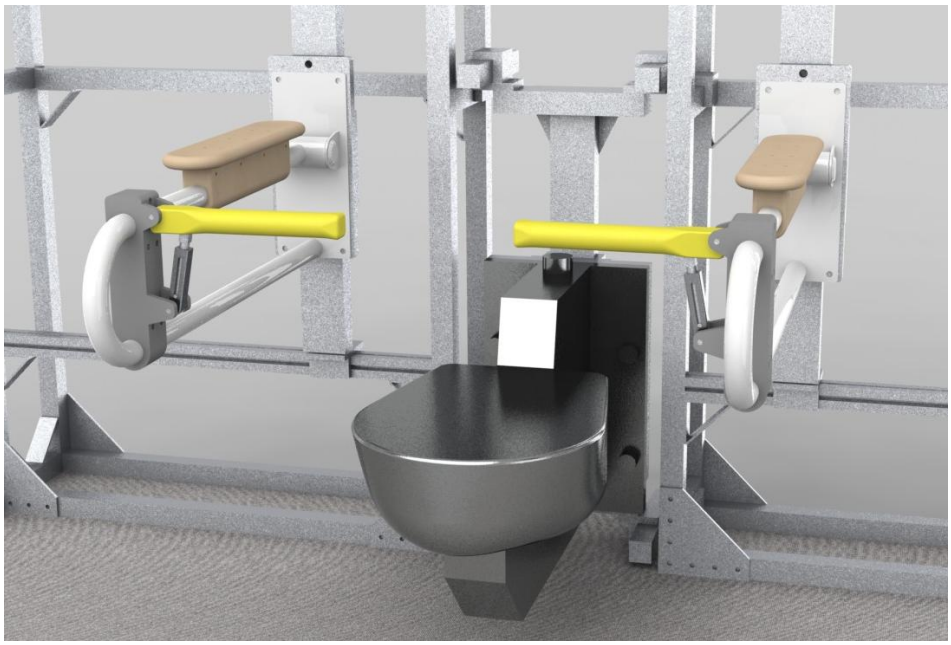


Figure 5.2 Computer model of the prototype in the context (short handles in horizontal position)

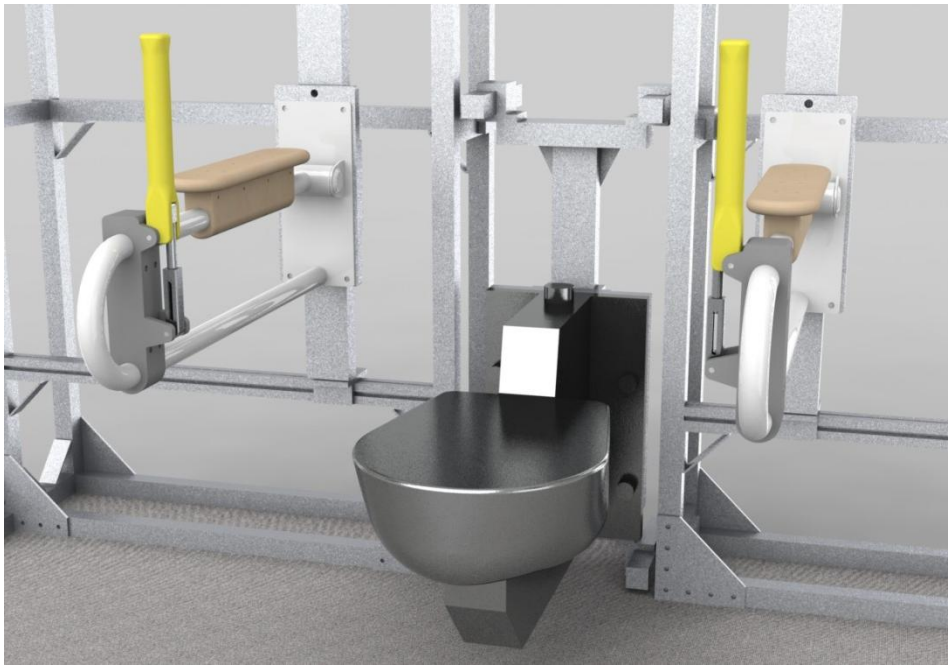


Figure 5.3 Computer model of the prototype in the context (short handles in veritical position)

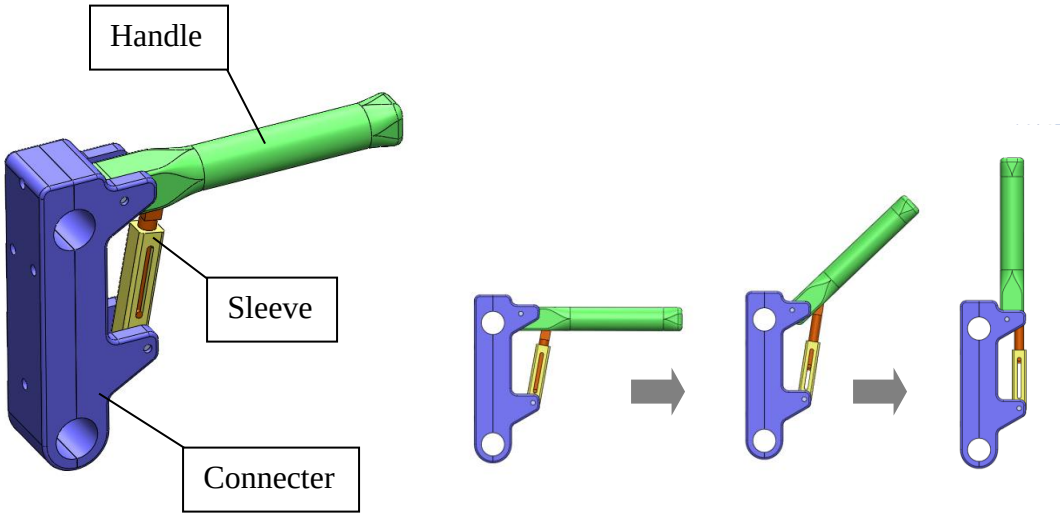
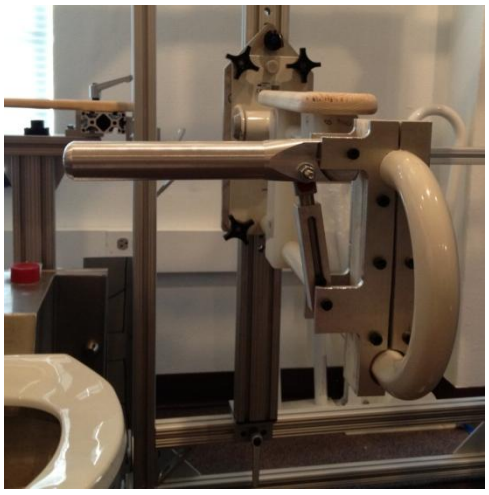


Figure 5.4 Computer model of the short handles

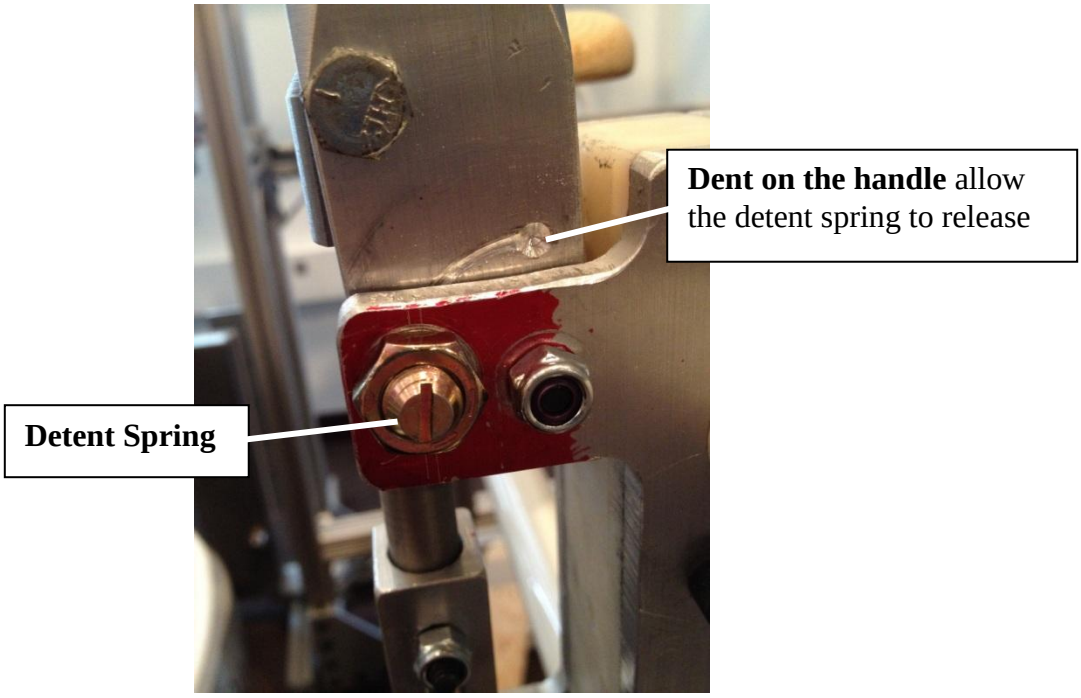
Table 5.1 Changes made to the short handles

	Original Plan	**Actual Design**
Material of the connecter	Plastic	Aluminum and plastic
Shape of the connecter	As shown in figure 5.4	All lines were made perpendicular or parallel to each other. No curves. Corners and edges were sanded round and smooth (Figure 5.5 (b)).
Shape of the handles	The diameter in the middle of the handle was a little smaller than the end (Figure 5.4).	The diameter of the handles was constant (Figure 5.5 (a)).
How to keep the handles stay in the vertical position	Wire springs inside the sleeve (Figure 5.4)	Detent springs (Figure 5.5 (c))



(a)

(b)



(c)

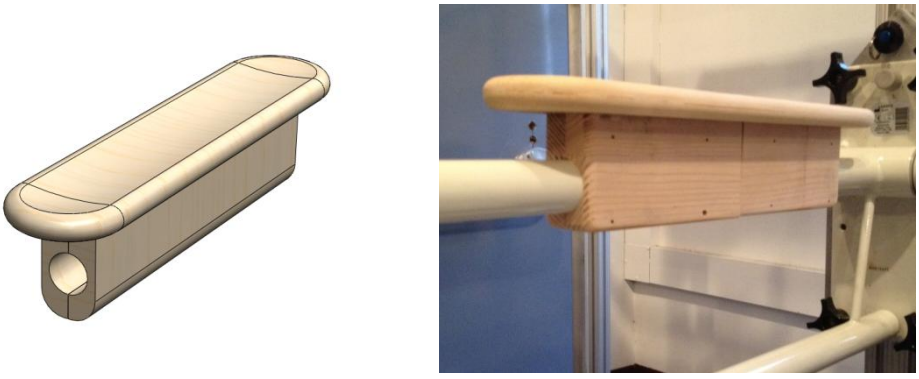
Figure 5.5

Figure 5.6 shows the computer model and the photos of two versions of the concave armrest we built in the prototyping phase. Table 5.2 summarizes the changes that were made on the armrest from version 1 to version 2. After version 1 armrest was mounted on the grab bar, because the connecter only clasped on one bar, the armrest rotated around the bar. Then I decided to use two connecters, the long one could clasp on both the top and the bottom bar. This would ensure that the armrest would not rotate. The material of the connecter was also changed in version 2. It was very difficult to make the semi-circle groove in the connecter using wood given our prototyping capabilities. In addition, the armrest needed to be taken on and off the grab bars many times during the testing phase, so making it out of plastic would be more durable.

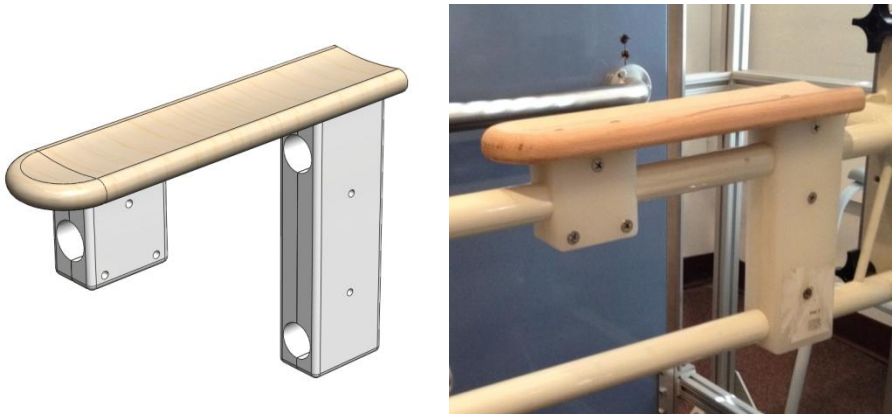
Another change from version 1 to version 2 was that the round back end of the armrest was eliminated in version 2 (Table 5.2). Some co-workers were asked to try version 1 armrest. For those whose forearms are longer than the armrest, when they put their forearm on version 1 armrest with their hand on the front end, their elbow hit on the back end because the top surface was concaved. There was also no need to make the back end a rounded shape because no one was likely to grab on that part.

Table 5.2 Changes made to the concave armrest

	Version 1	**Version 2**
Material of the connecter	wood	plastic
Design of the connecter	One connecter, two pieces	Two connecters: one short, one long, four pieces
Design of the armrests	The back end was round	The back end was straight



Version 1



Version 2

Figure 5.6 Two versions of the concave armrest

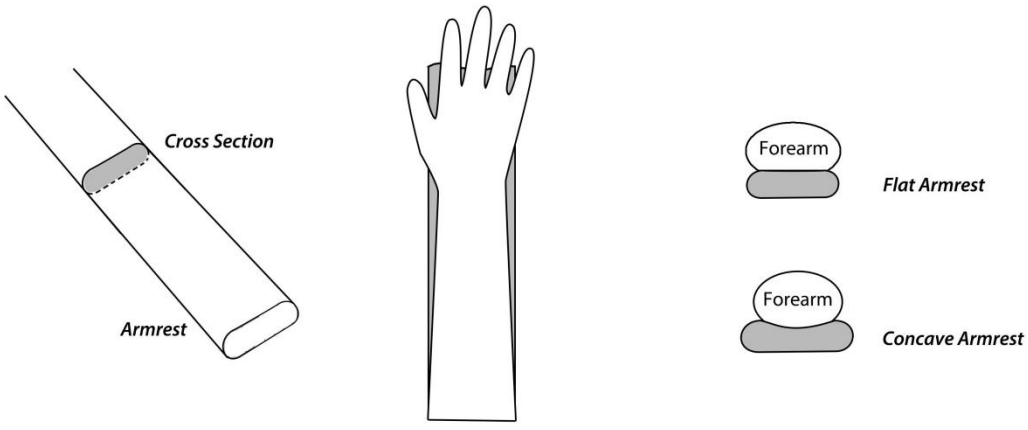


Figure 5.7

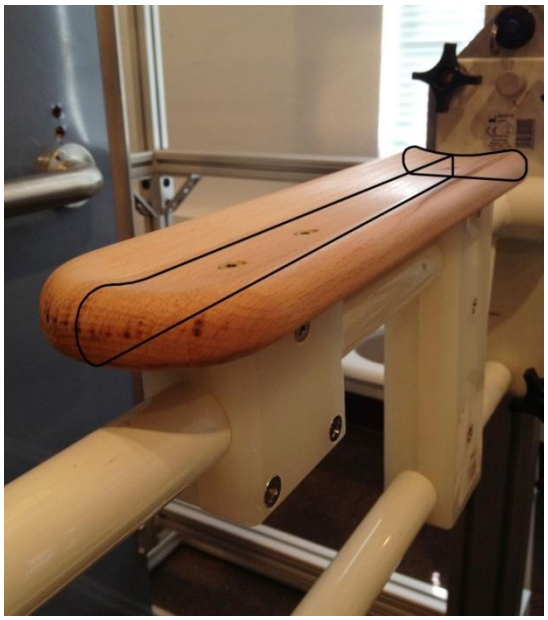


Figure 5.8 Concave Armrest

Figure 5.9 Flat Armrest

Based on the anthropometry data of palm width for men and women (Figure 5.10, Table 5.3 and Table 5.4), each armrest was built in 3 different widths to determine the optimized width. The flat armrest was made in 2.5”, 3” and 3.5” (Figure 5.11). The

concave armrest was made in 3”, 3.5” and 4” (Figure 5.11), which was 0.5” wider than the flat armrest because it needed to be wider to have the same support area as the flat armrest (Figure 5.7). These armrest models were tried out by co-workers and classmates who varied in arm size and hand size. The 4” concave armrest was unnecessarily too wide for most of them, and the 2.5” flat armrest was not wide enough. Both 3” and 3.5” armrests were comfortable to put arms on and grab on the end, but the 3.5” concave armrest was more comfortable than the 3” concave armrest for people who have wider arms. So we finally chose 3.5” as the width for both armrests in the testing. Then I sanded the 3.5” flat armrest and 3.5” concave armrest, rounded the edges and corners, and put clear coating on them (Figure 5.8 and Figure 5.9).

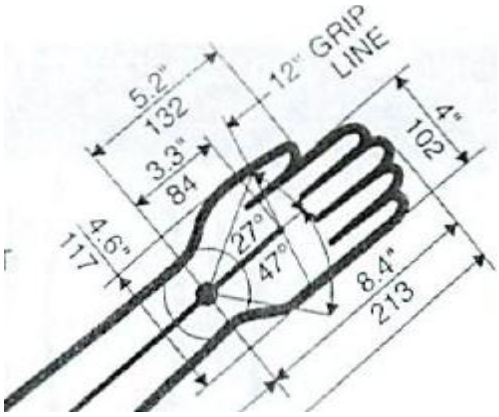


Figure 5.10 Measure of hand size (Tilley, 1993)

Table 5.3 Width of palm (excluding index finger) (Tilley, 1993)

95 percentile women	**50 percentile women**	**5 percentile women**
3.4”	3”	2.5”
95 percentile men	**50 percentile men**	**5 percentile men**
4”	3.4”	3.1”

Table 5.4 Width of palm (including index finger) (Tilley, 1993)

95 percentile women	50 percentile women	5 percentile women
4.1”	3.6”	3.2”
95 percentile men	**50 percentile men**	**5 percentile men**
4.6”	4.1”	3.7”

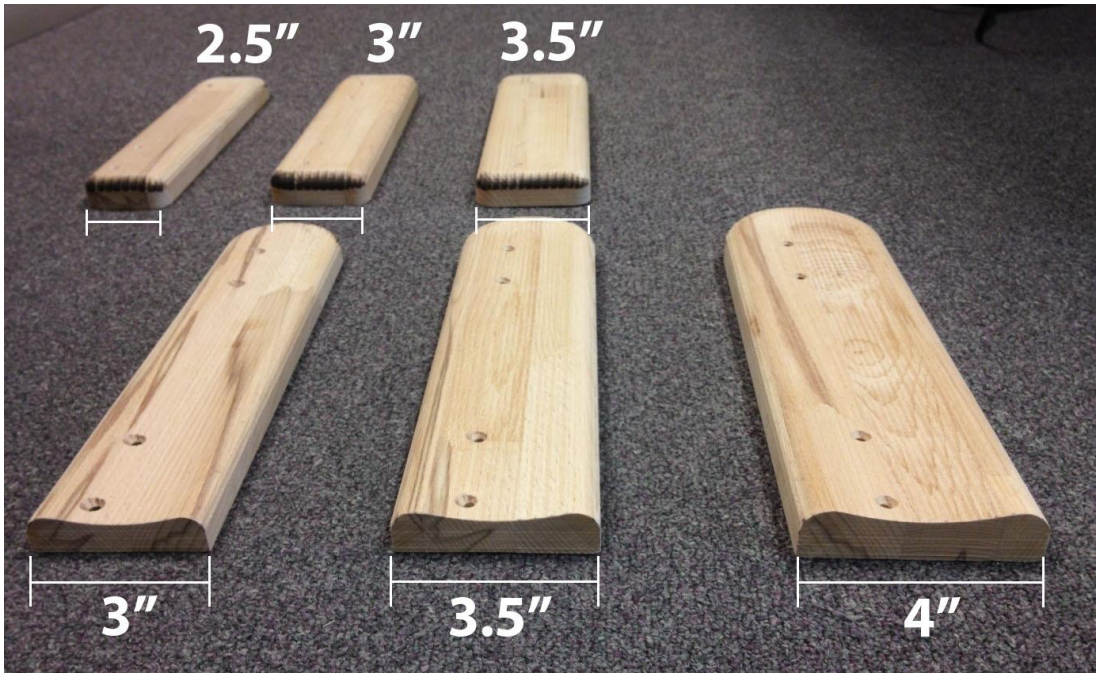


Figure 5.11

CHAPTER 6

USER TESTING

Methods

Experimental Design

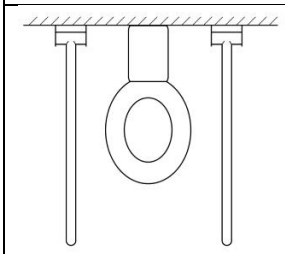
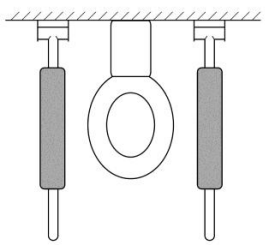
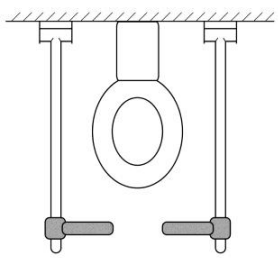
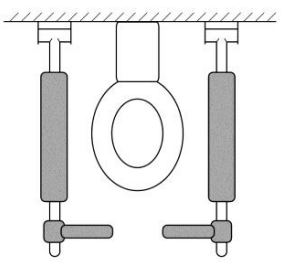
Because I wanted to know how the short handles and the armrests work separately and together, and I needed a baseline (grab bars without any attachments) to compare with, I decided to evaluate four grab bar configurations as shown in Table 6.1 by gathering data from questionnaire and video record. The questionnaire was aimed to evaluate the four configurations in terms of helpfulness, safety, ease and comfort from the perspective of the users. The video record would be used to assess how the grab bar configurations would be used by the subjects.

In the questionnaire, I asked questions "how helpful/safe/easy/comfortable were the grab bars/ armrests/ short handles for getting on/off the toilet" by giving five ratings which were from negative to positive as shown in Figure 6.1. For configurations GB+A, subjects were also asked to rate the length, width, and position of the armrests (Figure 6.2). For configuration GB+SH, subjects were asked to rate the diameter and length of the short handles. After using all configurations, subjects were asked to compare the four configurations in terms of safety, ease of use, and comfort, and to choose the overall best among the four (Figure 6.3). At last, they were asked open-ended questions about their opinions of the armrest and the short handles (Figure 6.4).

The video record was analyzed by marking which part (GB/A/SH/W) of the grab bar configuration was used in the six sequential steps in the transfer. So I can evaluate the effectiveness of the armrest and the short handles by summarize when the armrest or the

short handles were used and how often they were used. From the video record, it was also easy to know who used the armrests or the short handles often and how they interacted with them in order to find why the prototype succeeded or failed to assist standing transfer.

Table 6.1 Four grab bar configurations used in user testing

Grab Bars without any attachments (GB)	Grab Bars with Armrests (GB+A)	Grab Bars with Short Handles (GB+SH)	Grab Bars with both Armrests and Short Handles (GB+A+SH)
			

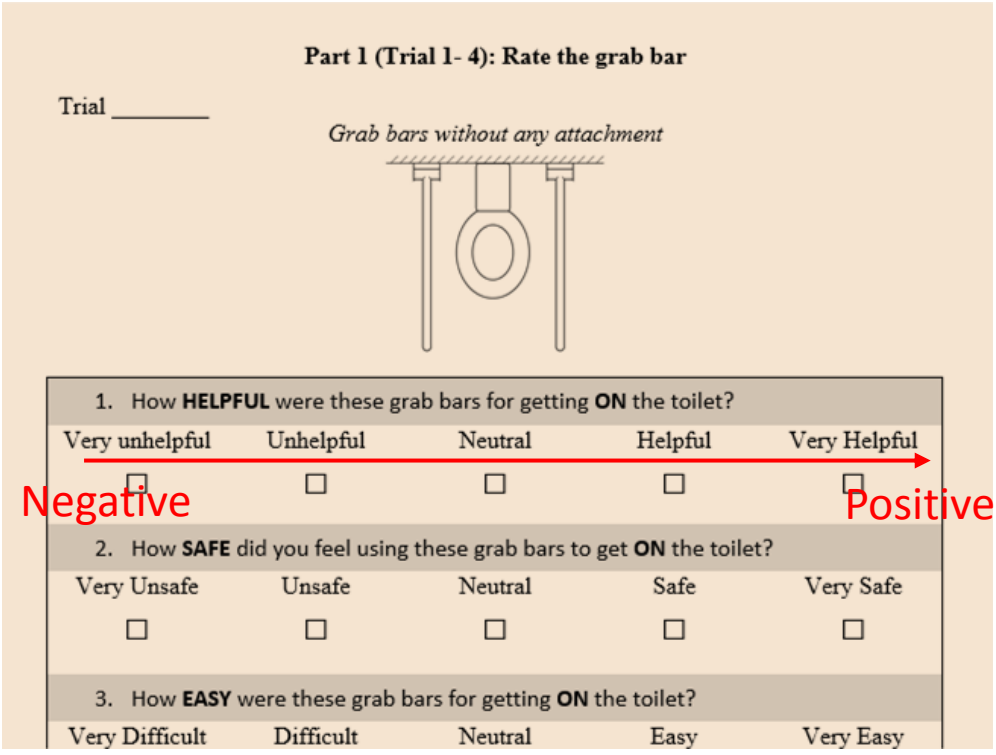
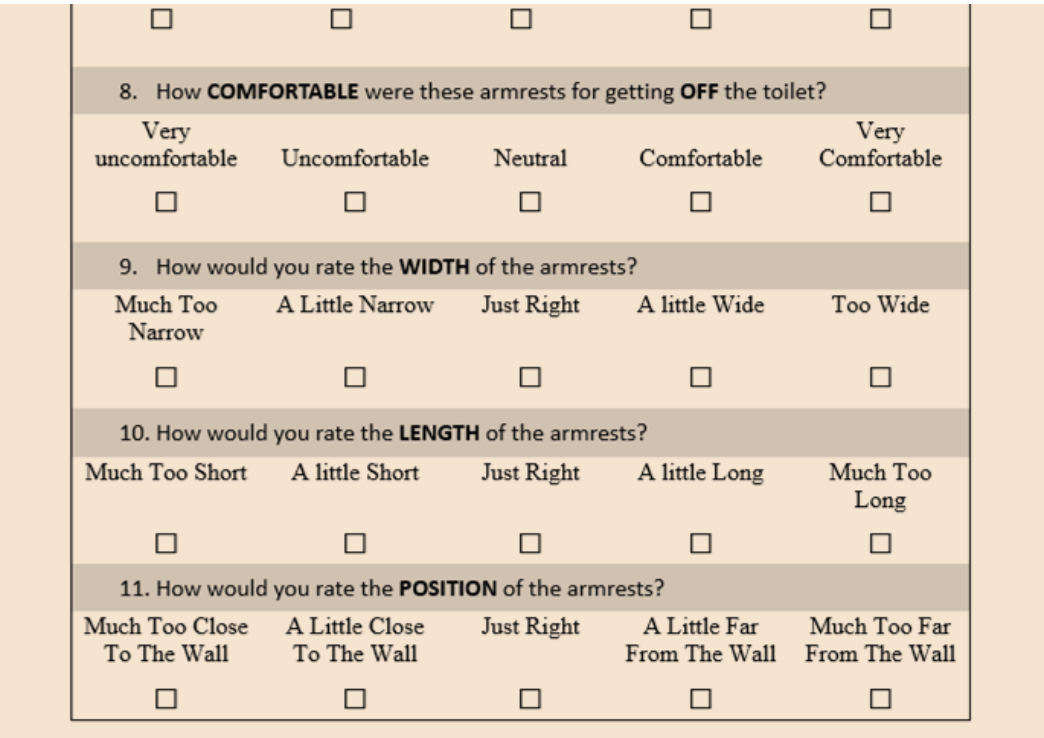
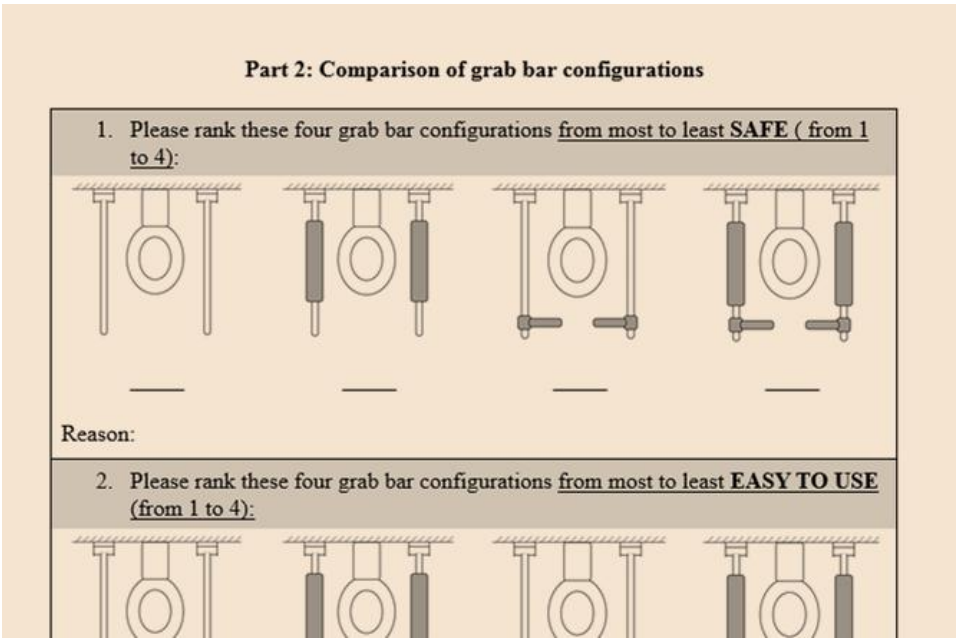


Figure 6.1 Questionnaire example 1



☐	☐	☐	☐	☐
8. How **COMFORTABLE** were these armrests for getting **OFF** the toilet?				
Very uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable
☐	☐	☐	☐	☐
9. How would you rate the **WIDTH** of the armrests?				
Much Too Narrow	A Little Narrow	Just Right	A little Wide	Too Wide
☐	☐	☐	☐	☐
10. How would you rate the **LENGTH** of the armrests?				
Much Too Short	A little Short	Just Right	A little Long	Much Too Long
☐	☐	☐	☐	☐
11. How would you rate the **POSITION** of the armrests?				
Much Too Close To The Wall	A Little Close To The Wall	Just Right	A Little Far From The Wall	Much Too Far From The Wall
☐	☐	☐	☐	☐

Figure 6.2 Questionnaire example 2



Part 2: Comparison of grab bar configurations

1. Please rank these four grab bar configurations from most to least **SAFE** (from 1 to 4):

____ ____ ____ ____

Reason:

2. Please rank these four grab bar configurations from most to least **EASY TO USE** (from 1 to 4):

Figure 6.3 Questionnaire example 3

Part 3: Questions and Concerns

1. Please tell us your likes and dislikes about the armrests in terms of safety, ease of use and comfort? Likes: Dislikes:
2. Please tell us your likes and dislikes about the short handles in terms of safety, ease of use and comfort? Likes: Dislikes:
3. Other questions?

Figure 6.4 Questionnaire example 4

Subjects + Recruitment

4 subjects participated in this testing. They are all older than 65, use wheelchairs and could independently transfer on the toilet from a standing position. It is important to note that it was very difficult recruiting subjects for this testing. At beginning, the recruitment materials were sent out through the CATEA Consumer Network to 65 people who live in Atlanta area, older than 65 and use wheelchairs. Because there was no response from this group of people, the age limitation in the recruiting criteria was modified to people age 55 and older in order to increase the number of recipients of the advertisement. Subject 1 responded to the second advertisement and decided to participate in the testing. While waiting for more responses and reaching out to senior living centers, I was able to get connected to a senior living center in Midtown Atlanta where 5 of their residents were interested in this study. One person was excluded because she was over 250 pounds. Another person decided not participating in this study because she thought she would not get her knee surgery done by doing this testing. Thus, 3 more

subjects decided to participate in the testing. Unfortunately I did not get more responses from other resources in the 5 months.

Test Equipment

The testing equipment was built as a portable testing system, which could be taken apart and transported to another location (Figure 6.5). It also has the ability to allow tester to adjust the height of the grab bars, the distance between the grab bars, the height of the toilet, and to move the toilet forward or backward. The grab bars can be moved in vertical direction at one inch intervals, and can be moved in horizontal direction continuously.

Figure 6.5 Testing equipment

Figure 6.6 A closer look of the grab bar configuration GB+A+SH

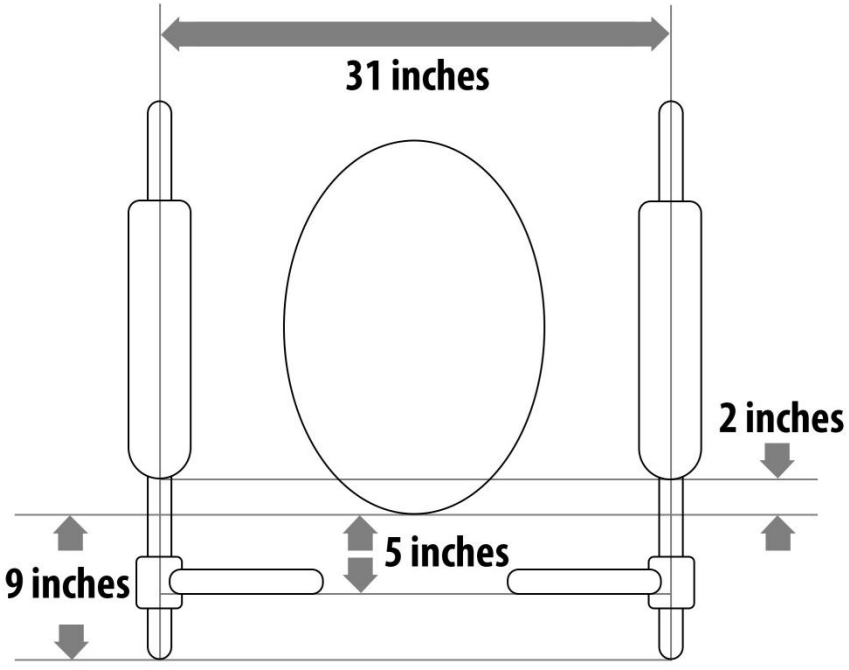


Figure 6.7 Dimensions of the testing set up

The Devon grab bars used in this testing were 30 inches long from the wall to the front end. The folding grab bars were set up following ADAAG: the height of the grab

bars was 31 inches (from the floor to the top of the grab bar, not including the armrests). The top of the armrests was 33 inches above the floor. Figure 6.7 shows most of the key dimensions of the initial testing set up. Distance between the two grab bars was 31 inches (From center line to center line). The distance between front of toilet and front of armrests was 2 inches. Distance between the front of toilet and the front of the grab bars was 9 inches. Distance between front of toilet and the front of short handles was 5 inches.

Procedure

All subjects were informed before the formal testing about the study through the flyer and the IRB consent form (Appendix). They were assigned into different time spot so that each subject did the testing without the presence of other subjects. Each subject transferred from the wheelchair to the toilet using four different grab bar configurations (Table 6.1), which were presented to them in a random order. For each configuration, the subject was told to try as many times as they wanted until they felt it was enough. After each trail, the subject was asked to rate the grab bar configuration just used in terms of safety, ease of use and comfort. After using the last configuration, the subject was asked to compare the four grab bar configurations and answered open-ended questions. With the subjects' permission, they were videotaped when they transferred between the toilet and the wheelchair using the grab bars.

Results

Please see Appendix E for the data summary of individual subject.

Observation of armrest use

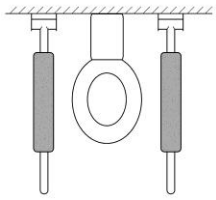
<u>When were the armrests being used more often?</u>

All subjects used the armrests for pivoting themselves to face away from toilet before they get on the toilet. Three out of four subjects used the armrests while they were

sitting down on the toilet. It was important to see that the armrests were seldom used alone. The grab bars were also frequently used at the same time (Table 6.2).

Table 6.2 Use of the armrests in configuration GB+A

Configuration - Grab Bars with Armrests (GB+A)



Process of Toilet Transfer		Subject 1	Subject 2	Subject 3	Subject 4
Getting on the toilet	Sit to stand from wheelchair facing toilet	GB **A**	GB With/without W	GB	GB
	Pivoting to face away from toilet	GB **A** with/without W	GB **A**	GB **A**	GB **A** With/without W
	Stand to sit onto toilet seat	GB **A**	**A** or GB	GB	GB or **A**
Getting off the toilet	Sit to stand from the toilet	GB	GB	GB	**A** or GB
	Pivoting to face toilet	GB **A** with/without W	GB W	GB W	GB **A**
	Stand to sit into wheelchair	GB **A** W	W	W	GB

GB=Grab Bars; A= Armrests; SH=Short Handles; W=Wheelchair.

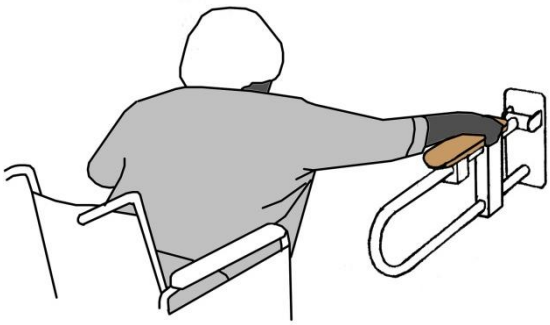
Who used the armrests more often? And how did they use the armrests?

Subject 1 used the armrests significantly more often than the other three subjects. She almost used the armrests for all steps except standing up from the toilet. She stated that she had weak wrists and she was short, so she preferred to put her weight on her

forearms rather than on her hands and wrists (Figure 6.8 (c)). For this reason, she bent her trunk forward more than other subjects did when she stood up from the wheelchair in order to put her forearm on the armrest (Figure 6.8 (a)). She also use only one grab bar (with or without armrests) at the same time as she pivoted and sat down on the toilet (Figure 6.8 (b) and Figure 6.8 (c)).

Subject 2 used the armrests when he sat down on the toilet seat by grabbing the front end of the armrests (similar to Figure 6.8 (e)). He also touched the armrest when he pivoted himself to face away from the toilet. Subject 3 only used the armrest once when she pivoted to face away the toilet.

Subject 4 used the armrests mainly for sitting down on the toilet and standing up from the toilet (Figure 6.8 (e)). She said that the armrests were needed as a rest for her arms especially when she sat on the toilet seat (Figure 6.8 (d)).



(a)

Subject 1 was pulling herself out of the wheelchair

(b)

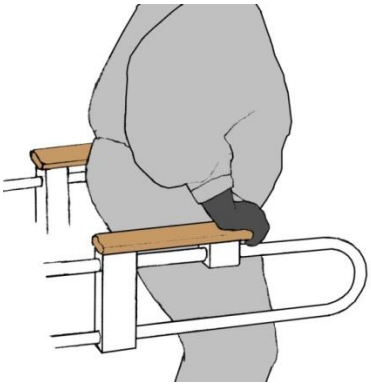
Subject 1 was pivoting when she got on the toilet

(c)

Subject 1 put her left forearm on the armrest

(d)

Subject 4 was sitting on the toilet seat



(e)

Subject 4 was standing up from the toilet

Figure 6.8 How subject 1 and subject 4 used configuration GB+A

Observation of short handle use

When were the short handles being used more often?

Except subject 1, all subjects used the short handles to help them stand up from the wheelchair, stand up from the toilet and sit down in the wheelchair (Table 6.3). The use of grab bars or wheelchair was significantly reduced when the short handles were used.

Who used the short handles more often? And how did they use the short handles?

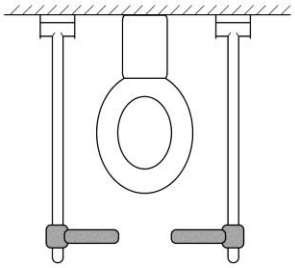
Subject 1 did not have the ability to pull herself up by grasping on the short handles due to her wrist problem. So in configuration GB+SH, she did not use the short handles at all.

Subject 2 mostly used the short handles to help him standing up from either the wheelchair or the toilet. He did not rely on the short handles when he was pivoting or sitting down on the toilet (Figure 6.9 (a) and Figure 6.9 (b)). He put his hands on the short handles while he was sitting on the toilet seat, with one short handle up and the other one down (Figure 6.9 (c)). When he stood up from the toilet, he kept the short handles one up and one down, but he put his left hand on the grab bar rather than the short handle.

Subject 3 and subject 4 put their hands on the short handles nearly all the time in configuration GB+SH, and they use the short handles in a similar way. Figure 6.10 illustrate how Subject 4 used the short handles in configuration GB+SH. She moved one short handle up and kept the other one down when she was about to turn around (Figure 6.10 (c)). She moved her left hand to the vertical handle, and kept turning until her right hand touching the horizontal handle (Figure 6.10 (d)).Then she sat down on the toilet with both hands grasping on the short handles (Figure 6.10 (e)).

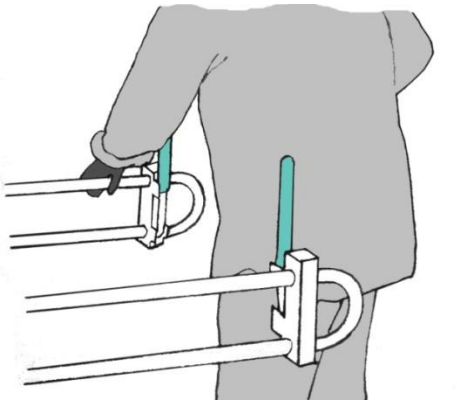
Table 6.3 Use of the short handles in configuration GB+SH

Configuration - Grab Bars with Armrests (GB+SH)



Process of Toilet Transfer		Subject 1	Subject 2	Subject 3	Subject 4
Getting on the toilet	Sit to stand from wheelchair facing toilet	GB with/without W	**SH**	**SH**	**SH**
	Pivoting to face away from toilet	GB with/without W	GB	**SH**	**SH**
	Stand to sit onto toilet seat	GB	GB	**SH**	**SH**
Getting off the toilet	Sit to stand from the toilet	GB with/without W	**SH** With/without GB	**SH**	**SH**
	Pivoting to face toilet	GB with/without W	GB with/without W	**SH** W	**SH**
	Stand to sit into wheelchair	GB with/without W	**SH**	**SH** with/without W	**SH**

GB=Grab Bars; A= Armrests; SH=Short Handles; W=Wheelchair.

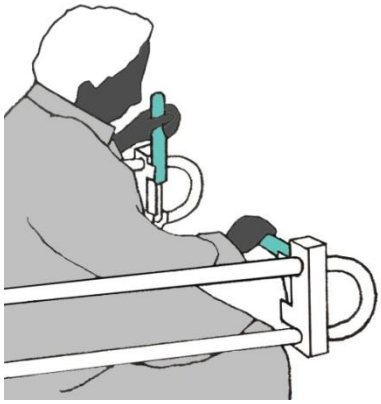


(a)

Subject 2 was pivoting when he got on the toilet.

(b)

Subject 2 was sitting down on the toilet.



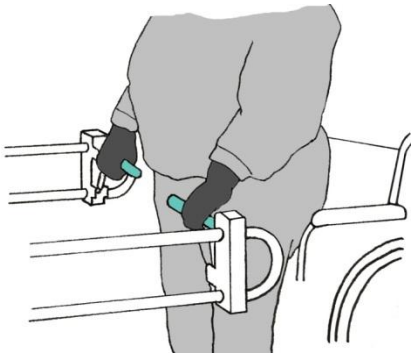
(c)

Subject 2 put his hands on the short handles while he was sitting on the toilet seat, with one short handle up and the other down.

Figure 6.9 How subject 2 used configuration GB+SH

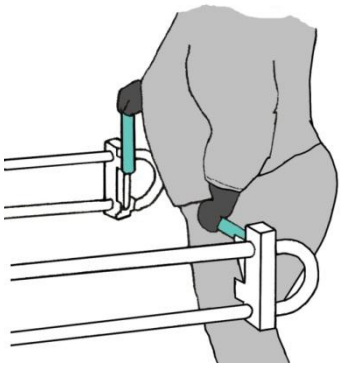
(a)

Subject 4 was pulling herself up from the wheelchair/sitting down on the wheelchair



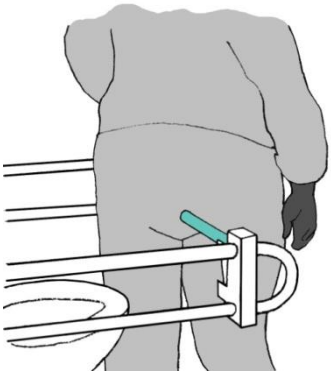
(b)

Subject 4 was standing when she was about to turn around



(c)

Subject 4 lifted up one short handle when she was turning around



(d)

Subject 4 was pivoting with her left hand grabbing on the short handle

(e)

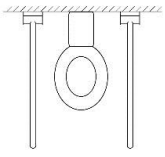
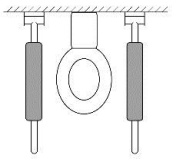
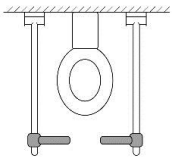
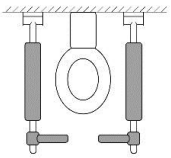
Subject 4 was sitting down on the toilet seat

Figure 6.10 How subject 4 used configuration GB+SH

Subject's ratings

Table 6.4 shows subjects' ratings of each grab bar configuration in terms of helpfulness, safety, ease of use, and comfort for both getting on and getting off the toilet. The negative and neutral ratings were highlighted in Table 6.4. There were no negative ratings to configuration GB+SH and ratings of configuration GB+A+SH were all positive.

Table 6.4 Ratings of grab bar configurations

Questions	Configurations / Answers	Grab Bars without any attachments (GB) 	Grab Bars with Armrests (GB+A) 	Grab Bars with Short Handles (GB+SH) 	Grab Bars with both Armrests and Short Handles (GB+A+SH) 
Q1. How **HELPFUL** were these grab bars for **GETTING ON** the toilet?	Very helpless				
	Helpless		**3**		
	Neutral		**2**	**1**	
	Helpful	1, 2, 3		4	1, 4
	Very Helpful	4	1, 4	2, 3	2, 3
Q2. How **SAFE** did you feel using these grab bars to **GET ON** the toilet?	Very unsafe				
	Unsafe				
	Neutral		**2, 3**		
	Safe	3		1, 4	4
	Very Safe	1, 2, 4	1, 4	2, 3	1, 2, 3
Q3. How **EASY** were these grab bars for **GETTING ON** the toilet?	Very difficult				
	Difficult				
	Neutral	**2**	**2**	**1**	
	Easy			4	4
	Very Easy	1, 4	1, 4	2	1, 2
Q4. How **COMFORT ABLE** were these grab bars for **GETTING ON** the toilet?	Very uncomfortable				
	Uncomfortable				
	Neutral		**2, 3**	**1**	
	Comfortable	1, 2, 3		4	4
	Very Comfortable	4	1, 4	2, 3	1, 2, 3
Q5. How **HELPFUL** were these grab bars for	Very helpless				
	Helpless		**2**		
	Neutral	**2**	**3**	**1**	
	Helpful	3		4	4

GETTING OFF the toilet?	Very Helpful	1, 4	1, 4	2, 3	1, 2, 3
Q6. How **SAFE** did you feel using these grab bars to **GET OFF** the toilet?	Very unsafe				
	Unsafe				
	Neutral	**2**	**2, 3**		
	Safe			1, 4	4
	Very Safe	1, 3, 4	1, 4	2, 3	1, 2, 3
Q7. How **EASY** were these grab bars for **GETTING OFF** the toilet?	Very difficult				
	Difficult				
	Neutral		**2, 3**	**1**	
	Easy	2, 3		4	4
	Very Easy	1, 4	1, 4	2, 3	1, 2, 3
Q8. How **COMFORT ABLE** were these grab bars for **GETTING OFF** the toilet?	Very uncomfortable				
	Uncomfortable				
	Neutral	**2**	**2, 3**		
	Comfortable			1, 4	4
	Very Comfortable	1, 3, 4	1, 4	2, 3	1, 2, 3

Overall Preference

As shown in Table 6.5, no subjects chose configuration GB as the overall best during the four grab bar configurations. Subject 1 chose configuration GB+A as the overall best. She said that she did not need the short handles. Subject 1 liked the armrests because they provided flatter surfaces for her forearms. She said the size and position of the armrests were just right for her.

Subject 2 and subject 3 chose configuration GB+SH as the overall best. They did not have comments on the armrests since they seldom use the armrests. They both chose configuration GB+A as the least safe, least easy, and least comfortable to use. Both subject 2 and subject 3 had an average shoulder width.

Subject 4 chose configuration GB+A+SH as her favorite. But she failed to stand up from the toilet seat using the short handles in configuration GB+A+SH, because the short handles located too close to her chest when she sat on the toilet. But she succeeded

standing up from the toilet seat using the short handles in configuration GB+SH. However, she stated at the end of the questionnaire that she loved the armrests and did not think that the short handles were necessary for her.

Table 6.5 Subject's overall preference of grab bar configurations

Subject	Gender	Age	Height	Shoulder Width	Configuration			
					Grab bars without any attachments (GB)	Grab bars with Armrests (GB+A)	Grab bars with Short Handles (GB+SH)	Grab bars with both Armrests and Short Handles (GB+A+SH)
Subject 1 to 3 had constant opinions towards the grab bar configurations:								
1	Female	61	Short	Wide		√		
2	Male	77	Average	Average			√	
3	Female	74	Tall	Average			√	
Subject 4 reported different opinions in different parts of the questionnaire:								
When asked about which configuration was the overall best:								
4	Female	82	Average	Wide				√
Summarized from her answers to the questions being asked after use of each configuration:								
4	Female	82	Average	Wide		√		

Likes and Dislikes

All subjects stated that the height and width of the grab bars were suitable for them. They also stated that the size (diameter and length) and position of the short handles were right. Both subject 1 and subject 4 who actually used the armrests reported that they noticed the difference between these two armrests. But they had differing opinions towards which one was better. Subject 1 liked the concave armrest (Figure 5.8) because the curvature of the concave fitted her arms, and she did not say that it was

uncomfortable to use. However, subject 4 did not feel like using the concave armrest because she had to put her arm in that concave otherwise she felt uncomfortable. The flat armrest (Figure 5.9) did not have the problem of fitting, it was more flexible to use than the one that has the concave.

Discussion

The short handles

What was found as a very important improvement of the short handles compared to existing grab bars was that the use of the wheelchair was largely reduced when the short handles were provided to the subjects. Subject 3 and Subject 4 finished the whole transfer process without touching the wheelchair when they used the configuration GA+SH. Although the number of subjects in this testing was too small to conclude that the short handles were significantly helpful in reducing the use of wheelchair during toilet transfer by older adults, it shows a promising direction for further grab bar designs.

The design of the short handles was intuitive. I did not tell the subjects how to use the short handles before their first trial and they all figured it out. Nearly every one put the short handles back to the horizontal position after they sat back in the wheelchair. It was probably because the short handles were set horizontal when they were exposed to the subject for the first time. But it was also possible that the subjects developed this habit because they thought the horizontal position would be needed in the next trial.

Some subjects chose to keep one handle horizontal and the other handle vertical while they were pivoting themselves in standing positions. It was possibly because they thought it was safer and easier for one hand to hold on the horizontal handle while the other hand was holding on the vertical handle (Figure 6.10 (c)), since the short handle was not locked at its vertical position. Further study may consider mechanisms to allow the user to lock the short handle at its vertical position, but should be aware that adding

the locking function to the short handles will probably introduce additional steps to the transfer process or require more efforts from the user, which needs to be tested carefully to ensure that older people can easily operate the locking function.

Since the position of the short handles was not changed in this testing, we cannot say the position was perfect. Actually, Subject 4 failed using the short handles to get up from the toilet in configuration GB+A+SH. Although she succeeded standing up from the toilet using the short handles in configuration GB+SH, I noticed that she lifted up the short handles in the process of standing. In contrast, when she stood up from the wheelchair, since the distance from the short handles to her body was far enough, she can grip the short handles with her arms extended. So moving the short handles more forward to increase the distance between the short handles and the toilet (Figure 6.11) might be advantageous. Because in this testing, the short handles were installed on existing grab bars, the position of the handles was restricted by the length of the grab bars, and they were not able to be moved further forward. Further studies may need to specifically look at the right position of the short handles by using longer grab bars or some other structures which allow the distance between the short handles and the toilet to be adjustable.

The short handles proved to be very helpful to most of the subjects in this testing. However we should be aware that some people may not have the ability to use them such as subject 1 who had wrist problems. The design of the short handles excluded people who are unable to grasp a round bar or unable to bare the weight while grasping a round bar. For these people, the design of grab bars should consider their ability and their strategy for toilet transfer.

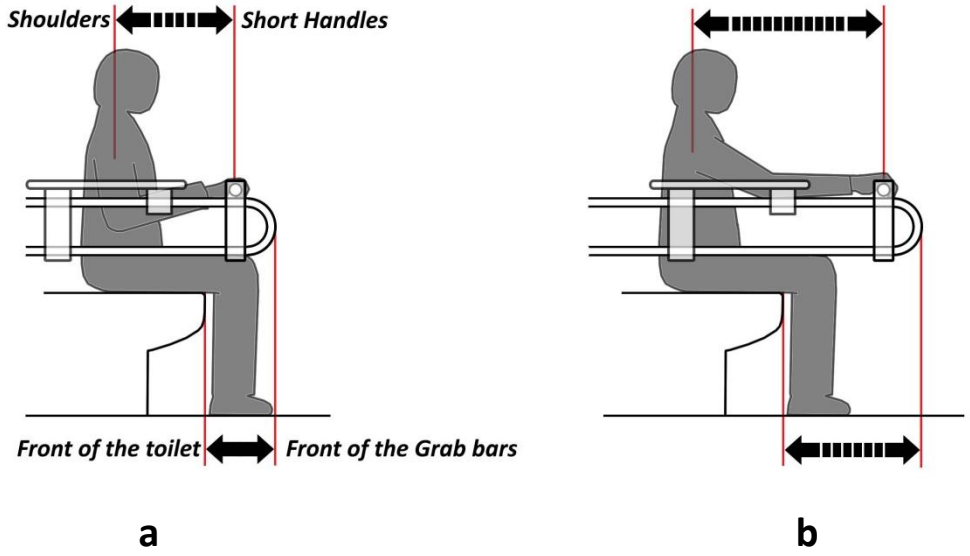


Figure 6.11

The armrests

The testing results showed that the armrests were very helpful to Subject 1 who had difficulty grasping the grab bars or the short handles. For other subjects, the armrests did not help them standing up from the wheelchair because the armrests were located out of reach while they were sitting in the wheelchair. Subject 1 and Subject 4 who preferred configuration with armrests were wider than Subject 2 and Subject 3who did not care about the armrests.

Because the location of the armrest was similar to the location of the folding grab bars to which the armrests were attached, the armrests were limited providing more help than the folding grab bars. When armrests were provided to the subjects along with the short handles, the armrests were used much less often than when they were provided without the short handles. This indicates that some functions of the armrests could be the same or similar to some functions of the short handles. In a future study, it will be worthwhile to define the functions of the armrests and the short handles based on testing through a larger group of users in order to find whether the armrests and the short handles have overlapped functions.

The design of the armrests may be an option for people who cannot grasp a round bar, but further studies are needed to look specifically at the physical ability of this group of people, how they transfer to the toilet and what are their needs in the transfer experience.

The detailed design of the armrests was not fully evaluated in this testing because the number of subjects was too small and only 2 subjects used the armrests for transfer. I would suggest that future designers or researchers evaluate different types of armrests in the context of toilet transfer and recruit more subjects for the testing.

The testing

The short handles and the armrests were not necessarily at the same level since some subjects only used the short handles and the other only used the armrests. For better understanding of each part, further study may design a prototype that can adjust the positions of the armrests and the short handles independently, or test them separately if they are not needed at the same time.

Although the original design of the questionnaire had a section to adjust the height and distance between the grab bars, the actual testing did not reach this level because all subjects did not think the positions of grab bars/ armrests/ short handles were uncomfortable for them. However we found the position of the short handles was not suitable for subject 4 even she did not state it. So it was possible that the subjects were not willing to do more trials by saying that the position of the prototype was appropriate for them. To avoid this, further study should let the subjects try grab bars in different positions without asking for their preference.

This testing lasted around one and a half hours for each subject, and I heard some subjects were lightly gasping after all trials even there was at least 10 minutes rest between each trail, so it was highly possible that if the time of testing is longer, subjects will feel more tired. Thus, if further testing needs to be longer or more demanding from

the subjects, instead of doing the whole testing for one subject at a time, researchers should consider dividing it into several shorter sections at different time to ensure that subjects will not be exhausted.

The testing did not collect anthropometry data (such as arm length, seated arm reach capacity, standing reach capacity) of each subject which was considered to be useful afterwards to analyze the relationship between the position of the prototype and the subjects. Further study should take this into consideration for better analysis of the effectiveness of the design.

CHAPTER 7

FINAL CONCEPTS

Final Concepts

The following findings from the testing were useful to revise the design:

The short handles

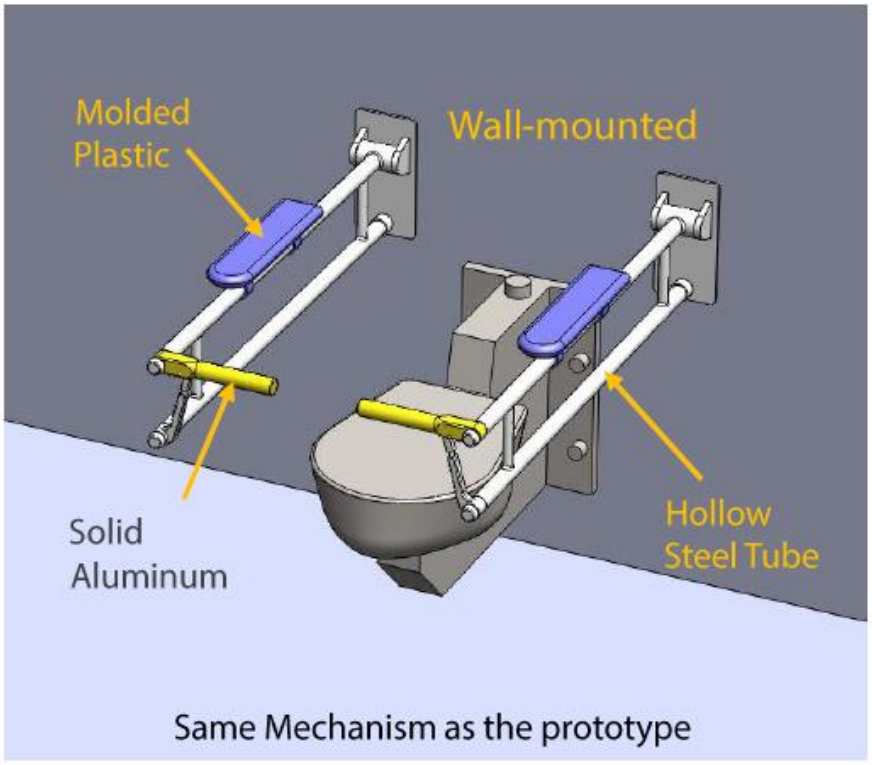
- The distance between the short handles and the front of the toilet needs to be increased to better assist older adults to stand up from the toilet seat.
- People may grab on the end of the short handles while they were pivoting themselves in standing positions.
- People may hold on the hinge of the short handles when they get up from the toilet seat.

The armrests

- The top surface of the armrest should be flat if the armrest is made out of hard materials.
- The top surface of the armrest could be concaved if the armrest is made out of softer material or has cushion layer on the top.

Figure 7.1 is the first concept generated based on the prototype. In this concept, instead of mounting the short handle on an existing grab bar through a connecter, the short handles are directly assembled to the end of the top bar. The mechanism of the short handles is exactly the same as that used in the prototype. The armrest in this concept (Figure 7.2) has the same size as the concave armrest except that the top surface is flat if it is made out of hard materials.

One advantage of this design is that it is easy to make it in different lengths (Figure 7.3) so that when toilets come in different sizes we can choose an appropriate grab bar to keep the distance between the short handles and the front of the toilet unchanged. Although concept 1 did not consider revising the design of the short handles and the overall shape of the skeleton, it is a feasible concept to be built require less tooling for molding, and it would definitely work as the same as the prototype.



Metal parts metal extrusion, welding, and machining
Plastic part molding/machining

Figure 7.1 Final Concept 1

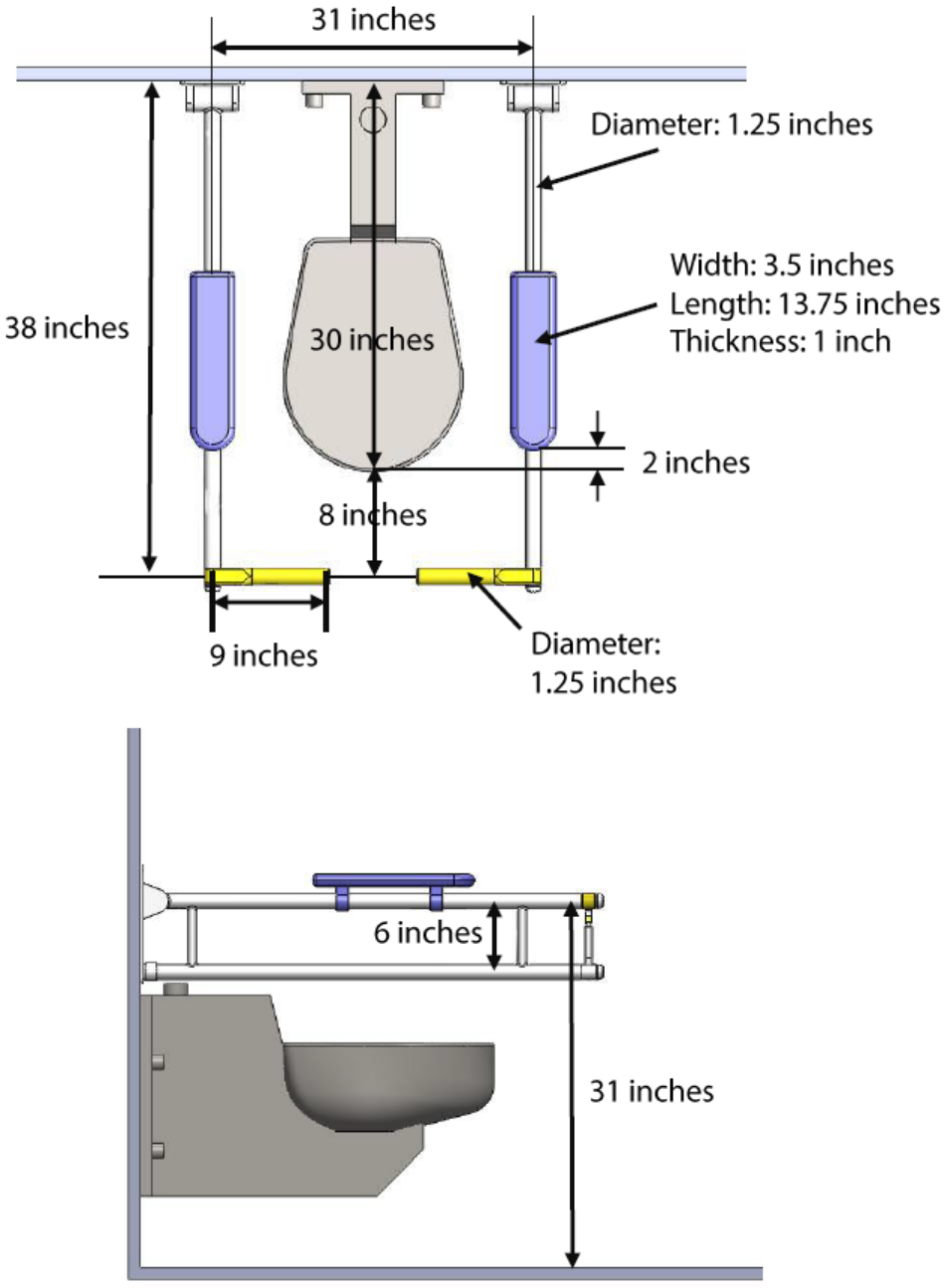


Figure 7.2 Dimensions of Final Concept 1

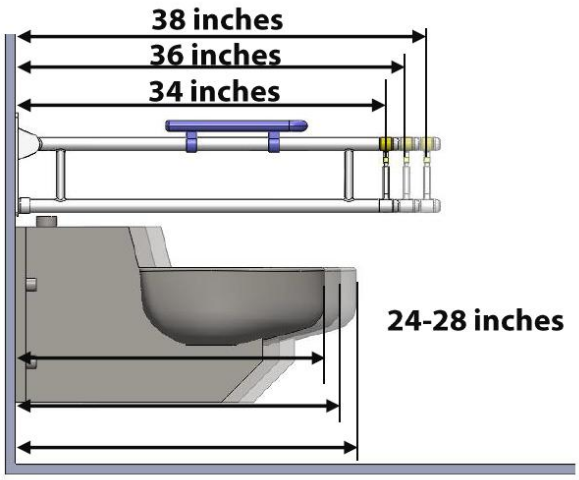


Figure 7.3

Concept 2 integrates the armrests and the short handles to the skeleton (Figure 7.4) and creates a cleaner and more appealing appearance. The key dimensions of concept 2 (Figure 7.5) are the same as concept 1. The length of the grab bar needs to be long enough so that the distance from the front of the toilet to the short handles is far enough. Figure 7.6 shows how the shape of the side profile evolves and Figure 7.7 shows three ideas that look similar but are different in how the armrest, the lower bar and the connecting part integrate with each other, which results in different materials and construction plan. Because of the cantilever structure and considering the weight capacity, all concepts have a lower bar underneath the armrest for structural purpose.

The mechanism for locking the short handle in vertical position would be the same as we used in the prototype. The detent spring near the hinge will lock the handle in place under certain amount of force, so the handle could be rotated if the users exert enough force to it. However in concept 2 the handle does not have the link that supports it from the side. So the stability of this structure needs to be tested and the handle may need to be made out of material with high rigidity.

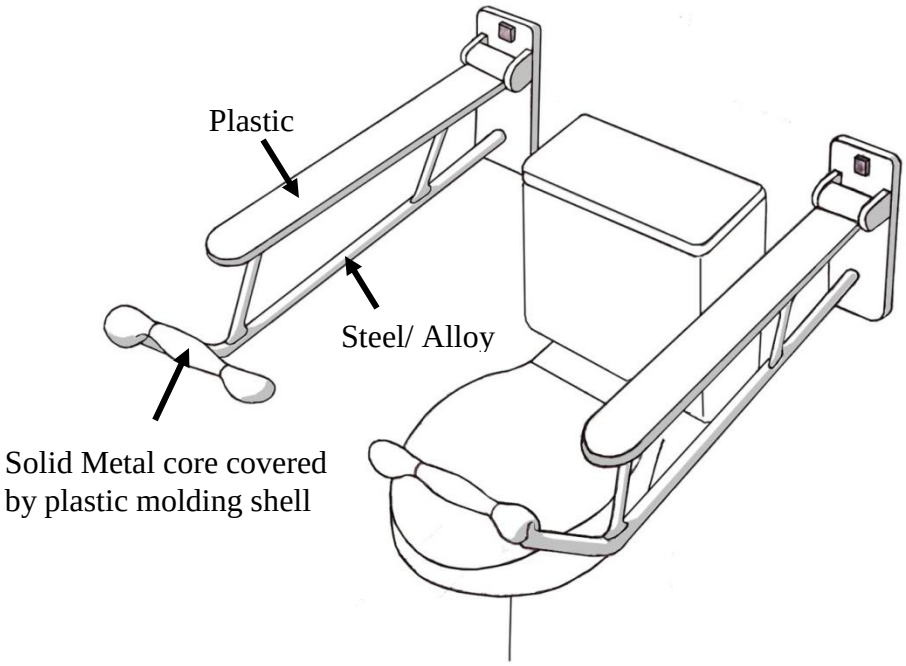


Figure 7.4 Final Concept 2

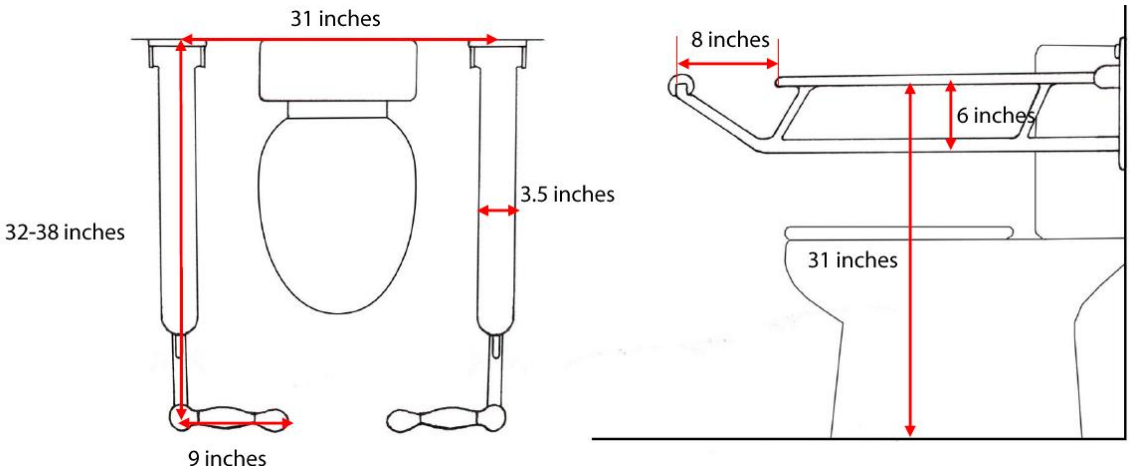


Figure 7.5 Dimensions of Final Concept 2

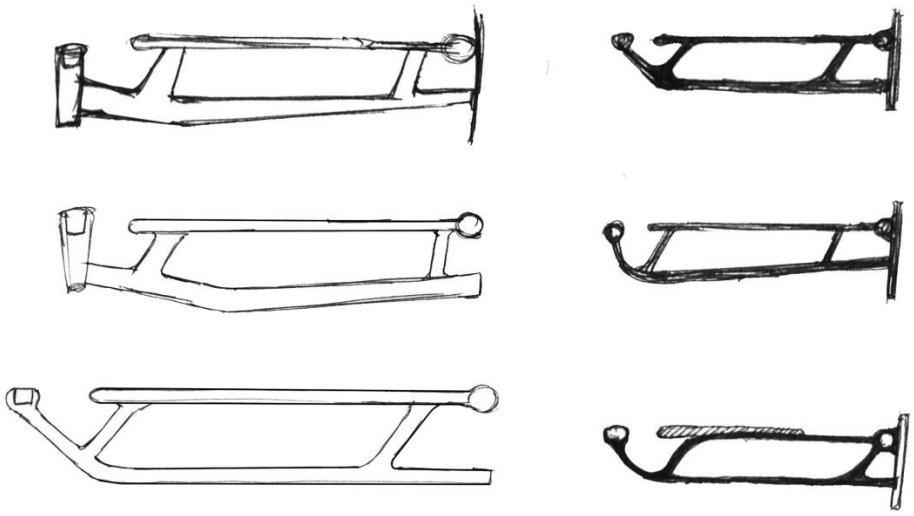


Figure 7.6 Evolution of side profiles

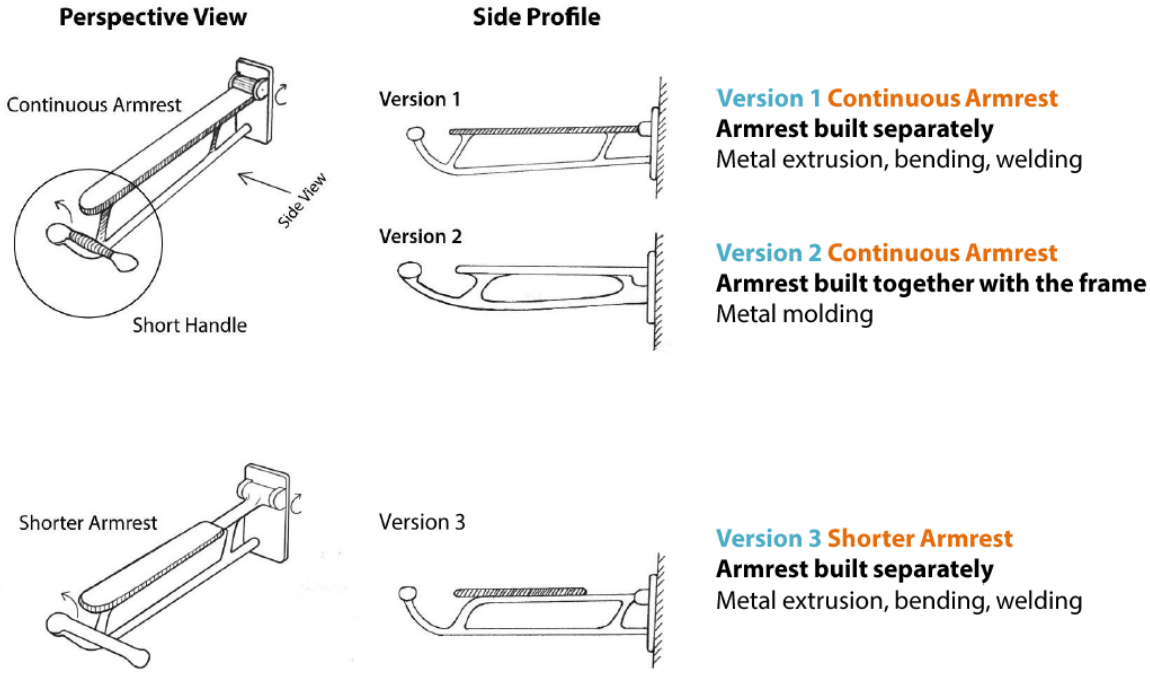


Figure 7.7 Different side profiles

Figure 7.9 shows the design for short handles. The shape of the handle is created based on how people would use it in different ways as observed in the testing. The

middle portion of the handle would be gripped by hand for pulling when people stand from a sitting position, and the end of the short handle would be grabbed as people pivot themselves while they are standing. The diameter of the middle portion of the short handle should be with 1 ¼ inches to 1 ½ inches, not only to follow ADAAG but also it would be comfortable to use for most people (Kong, 2005). Figure 7.8 shows ideations of the end portion of the short handle. The final shape was inspired by the shape of car transmission knob because the way how people grab on the end of the transmission knob was similar to the way how subjects grip the end of the short handles in user testing. The end portion is bigger than the middle portion, but it becomes narrower towards the middle portion, not only for integration to the middle portion, but also to fit the shape of the hand and to increase the graspability by providing more space for fingers. The size of the end portion should not exceed 2 inches (ADAAG).

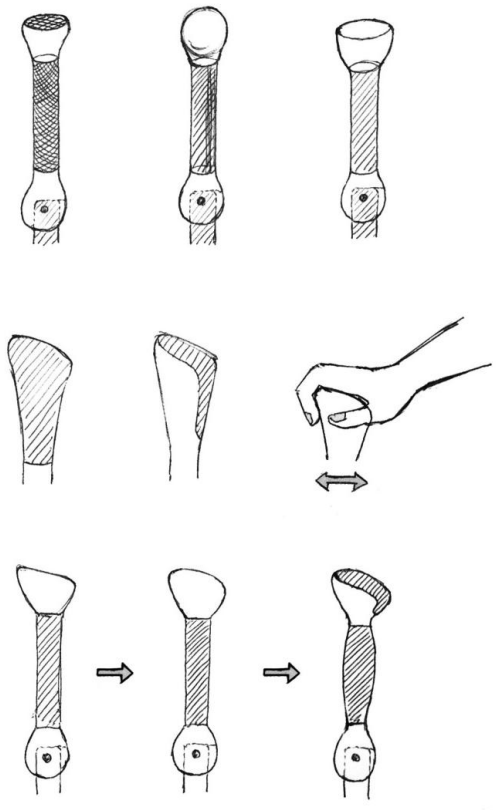


Figure 7.8 Evolution of short handle

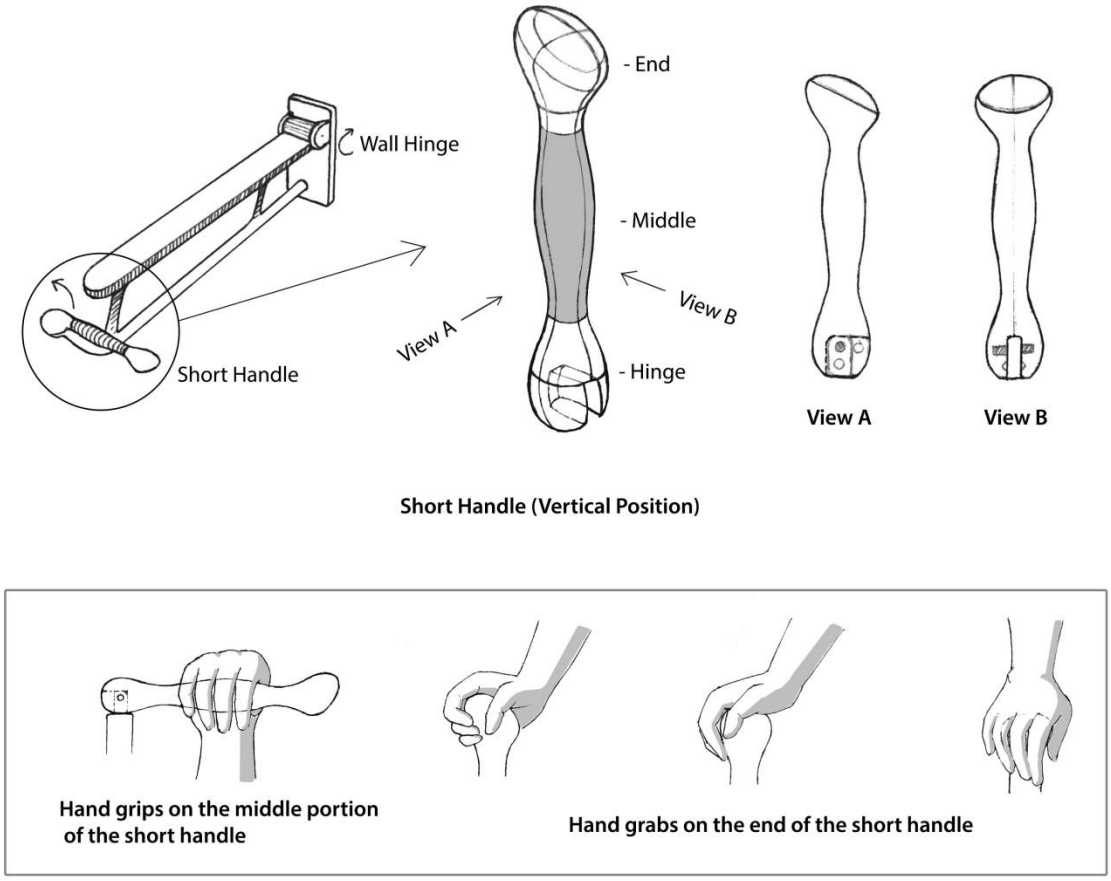


Figure 7.9 Details of the short handle

It will be worthwhile to build the short handles in different shapes and sizes (as shown in this chapter) in order to find the optimized form, but it has not been done within the timeframe of this project.

At this point, material, engineering and manufacturing difficulties have not been fully explored. It is suggested that the skeleton and the short handle are made out of metal or other materials that can bear the weight from the user. The skeleton can be built by welding a couple of pieces; each piece may require extrusion and bending. The skeleton can also be built by molding, however, the intensity and rigidity of the skeleton may be weaker than skeleton made by extrusion.

The armrest could be made out of plastic as long as it can stand the force that people would exert to it. It may be helpful to add a layer of cushion on the top surface of the armrest to make it more comfortable to use, but the end of the armrest needs to be firm because people would push on it.

As the whole product would be used in the bathroom, the surface should be resistant to moisture, mold, and water. The short handle may have texture on the surface to increase its graspability, and different portions (end, middle, and hinge) may have different color or texture to indicate that these portions would be used differently.

Conclusion

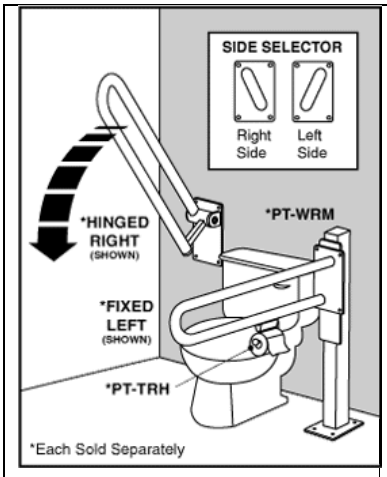
This project successfully developed a solution to problems defined through research of previous study. The outcome of this project includes not only things that worked, but also things that did not work, and the entire design process from the very beginning to the very end. A great amount of time was spent on figuring out the mechanism for short handles. And it took us five months to recruit the subjects for user testing, which was unexpected. Further researchers/designers should be aware of the amount of work when they define the scope of their projects at the very beginning, and be prepared to face unexpected situations that may occur and may influence the timeframe of the project.

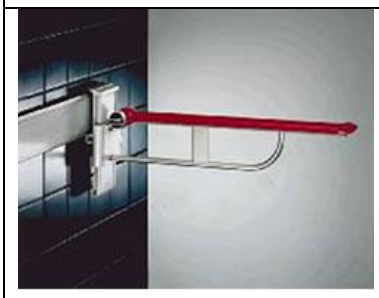
APPENDIX A

EXISTING GRAB BARS ON THE MARKET

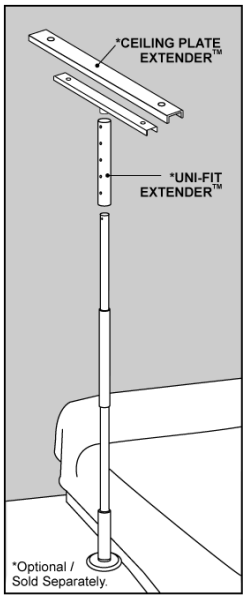
Table A.1

	**Elcoma Flip Up - Swing Up Grab Bars** Manufacturer: ELCOMA Metal (US) Features: locking hinge Material/finish: heavy duty die cast alloy for the hinge bracket; Stainless steel; Steel (powder coated) Weight Capacity: 250 lbs Installation: Wall or Floor mounted Price: from $210 to $ 305, depending on the length and material
	**Flip-up Safety Rail with Open Loop & "Friction Hinge"** Manufacturer: ELCOMA Metal (US) Features: friction hinge Material/finish: heavy duty die cast alloy for the hinge bracket; Stainless steel; Steel (powder coated) Weight Capacity: 250 lbs Installation: Wall or Floor mounted Price: $127.95, $ 210 to $ 255

	**The P.T. Rail** Manufacturer: Health Craft Products(Canada) Features: Offset rail design allows for improved use of the lower rail and helps to prevent wrist strain when reaching for the lower rail. Material/finish: Stainless Steel; Steel (bright polished Chrome; platinum Grey; powder coated white) Weight Capacity: 400 lbs Installation: Wall or Floor mounted Price: $194 (28 inches long) to $ 308 (32 inches long)
 	**Hinged arm support** Manufacturer: Linido (Netherlands) Features: These flip-up arm supports come in various lengths. They lock automatically in the upright position; have plastic wall plate. Material/finish: coated steel Weight Capacity: 330 lbs static pressure for vertical bar; 220 lbs static pressure for horizontal bar. Installation: Wall or Floor mounted Price: $179
	**Double Fold-up Support Bar w/ Adjustable Leg** Manufacturer: unknown Features: vertical bar adds weight support. Material/finish: steel, powder coated white Weight Capacity: 441 lbs Installation: Wall Mounted Price: $215.99

	**Optima Lockable Support Rail** Provider: Patterson Medical (US) Features: vertical bar adds weight support. Weight Capacity: 286 lbs Installation: Wall Mounted Price: $219.99
	**Pressalit Support Arm** Manufacturer: Pressalit Care (Denmark) Features: Folds up to wall with counter balance, Locking height adjustment, 10" height adjustment range Weight Capacity: 463 lbs Installation: Mount to horizontal wall track for lateral adjustment or mount directly to wall Price: start from £172 (not including VAT)
	**Adjustable Gated Foldaway Support Rail** Supplier: Nottingham Rehab Supplies (UK) Features: For use beside a toilet or shower seat. The swivel arm action provides security on the toilet preventing forward movement of client. Can be used on the left or right. Material: Die cast Aluminum coated back plate and steel arm. Weight Capacity: 182 lbs Installation: Wall Mounted Price: £142.97 (Including VAT)

 	**Folding Support System** Supplier: Nottingham Rehab Supplies (UK) Features: height adjustable and can be folded up against the wall when not in use. Includes front rails, back and side supports and strap. Weight Capacity: 294 lbs Installation: Wall Mounted Price: The Front Rails Kit is priced £346.21 (including VAT), the whole system is priced £1276.60 (including VAT)
	**Floor Mounted Folding Rail** Manufacturer: Devon (UK) Features: height adjustment Weight Capacity: 280 lbs Installation: Floor Mounted Price: $232.79
	**Elite Floor Mounted Folding Support Rail** Manufacturer: Devon (UK) Features: height adjustment, lightweighted, elliptical profile provide better grip Weight Capacity: Installation: Floor Mounted Price: £169.95 (not including VAT)

	**OFF-THE-POT** Manufacturer: Invisible Caregiver Innovations LLC (US) Weight Capacity: 350 lbs Installation: Wall or Floor Mounted Price: $399
	**Ringwood Wall-to-Floor Grab Rail** Manufacturer: unknown For easy storage & transportation the rail comes in two pieces and is self assembly (by a simple but extremely strong bullet catch mechanism). Weight capacity: 250 lbs Installation: Wall and Floor Mounted Price: $ 45.19 (1 Piece) (Price vary depending on the supplier)
	**Super Pole** Manufacturer: HealthCraft Product (Canada) Features: Ease of Installation; Foam hand grip provides a comfortable gripping surface, particularly useful for those with limited hand strength; Installs anywhere there is a floor and ceiling, placing transfer support directly where it is needed. Material: steel, powder coat white gloss finish Weight Capacity: 300/450 lbs Installation: Floor Mounted Price: $155 (google shoppping)

	**Super Pole with Super Bar** Manufacturer: HealthCraft Product (Canada) Features: unlocks and pivots freely to move with you step by step, yet locks every 45 degrees to assist with standing and sitting. Permits pulling up to standing and can provide leaning support while managing clothing. Material: steel, powder coat white gloss finish Weight Capacity: 300/450 lbs Installation: Floor mounted Price: $224 for the whole product; $95 for the add-on kit (google shopping)
	**Advantage Pole** Manufacturer: HealthCraft Product (Canada) Features: designed to be used where the ceiling height or structure will not accommodate a floor to ceiling pole. Material: steel, powder coat white gloss finish Weight Capacity: 450 lbs Installation: Floor mounted Price: $157.95 (Amazon)
	**Advantage Pole with Advantage Bar** Manufacturer: HealthCraft Product (Canada) Features: Locking feature provides excellent stability while pulling laterally for transfers. Five heights for the vertical bar. Material: steel, powder coat white gloss finish Weight Capacity: 300/450 lbs Installation: Floor mounted Price: $285 (google shopping)

	**Security Pole & Curve Grab Bar** Manufacturer: Stander (US) Features: Adjustable fits ceiling heights. The Curved Grab Bar also pivots, locking in place at eight different points (every 45 degrees). Weight Capacity: Installation: Tension mounted. Wall mounts are not needed; can be moved to any room in your home whenever necessary. Price: start from $147 (google shopping)
	**Handi-Grip Portable Grab Bar** Manufacturer: Roth Weight capacity: over 135 lbs. of suction power. Not designed to support the whole body. Installation: Easily installs and uninstalls in seconds, making it ideal for travel; Does not require any drilling and will not damage your bathroom walls. Price: $135.70 for the shortest one

APPENDIX B

OBSERVATION DATA

37 (32 Male, 5 Female) subjects use Swing-up configurations, 29 (26 Male, 3 Female) of them also use ADA configurations. People who did not stand onto toilet and people who did not use wheelchairs were excluded from the data.

Please see Table B.1 for the observation note which I used to code the transfer process. Table B.2 is the aggregation data of the use of folding configuration and wheelchair by 37 subjects. Table B.3 is a summary of Table B.2. Table B.4 shows the summarized data from 29 subjects who use both the folding configuration and the ADA configuration.

Table B.1 Observation Note

Tape#_____ Date_____ Subject #_____ Gender _____

Swing-up Configuration

Process		Grab Bar Zone																		Wheelchair		
		A									B											
		Top					Curve	Bottom			Top					Curve	Bottom			Armrest		Other
		5	4	3	2	1		1	2	3	5	4	3	2	1		1	2	3	A	B	
Getting ON the toilet	Getting off the wheelchair																					
	Turning/Pivoting																					
	Sitting down																					
Getting OFF the toilet	Getting up																					
	Pivoting																					
	Getting on the wheelchair																					

ADA configuration

Process		Grab Bar		Wheelchair
		Side Bar	Rear Bar	
Getting ON the toilet	Getting off the wheelchair			
	Turning/Pivoting			
	Sitting down			
Getting OFF the toilet	Getting up			
	Pivoting			
	Getting on the wheelchair			

Table B.2: Aggregation of Data

Process		Folding Configuration																		Wheelchair		
		A									B											
		Top					Curve	Bottom			Top					Curve	Bottom			Armrest		Other
		T5	T4	T3	T2	T1		B1	B2	B3	T5	T4	T3	T2	T1		B1	B2	B3	A	B	
Getting ON the toilet	Getting off the wheelchair	1	0	4	2.5	**12**	1.5	0	0	0	0	0	1	2.5	**11.5**	2	1	0	0	**13**	**14**	1
	Turning/Pivoting	0	2	6	7.5	**12.5**	0	0	0	0	0	1	11	6.5	**15.5**	1	0	1	0	6	4	1
	Sitting down	0	2	3	7	**16**	1	2	3.5	0.5	0	1	1	8	**13**	3	3	4.5	1.5	1	3	0
Getting OFF the toilet	Getting up	0	1.5	2.5	4	**15**	5	0	1.5	3.5	0	1	0.5	4.5	**16.5**	5.5	2	1.5	2.5	3	2	0
	Pivoting	1	1.5	6.5	5.5	**10.5**	0	1	0	0	0	0	2	2	**11**	1	1	0	0	**17**	**13**	1
	Getting on the wheelchair	0	0	0	0.5	7.5	0	0	0	0	0	0	0	1.5	8	1.5	0	0	0	**19**	**16**	1
Whole process		2	7	22	27	73.5	7.5	3	5	4	0	3	15.5	25	75.5	14	7	7	4	59	52	4
Total Use of GB/WC*		302																		115		

*GB=Grab Bars; WC=Wheelchair

1= user's hand was located in the zone

0.5=user's hand was located in two adjacent zones, each of which was scored 0.5.

Table B.3 Summary of Table B.2

Process		Folding Configuration									Wheelchair
		Top					Curve	Bottom			
		T5	T4	T3	T2	T1		B1	B2	B3	
Getting on the toilet	Getting off the wheelchair	1	0	22	5	23.5	3.5	1	0	0	28
	Pivoting	0	3	10	14	28	1	0	1	0	11
	Sitting down	0	3	4	15	29	4	5	8	2	4
Getting off the toilet	Getting up	0	2.5	3	8.5	31.5	10.5	2	3	6	5
	Pivoting	1	1.5	8.5	7.5	21.5	1	2	0	0	31
	Getting on the wheelchair	0	0	0	2	15.5	1.5	0	0	0	36
Whole process		2	10	37.5	90	149	21.5	10	12	8	115
Total Use of GB/WC*		250.5					21.5	30			115

*GB=Grab Bars; WC=Wheelchair

Table B.4 Comparison between ADA and Folding Configuration

Process		ADA Configuration			Folding Configuration		
		Grab Bar		Wheelchair	Grab Bar		Wheelchair
		Side Bar	Rear Bar		A	B	
Getting ON the toilet	Getting off the wheelchair	12	1	24	16	13	22
	Turning/Pivoting	25	2	8	22	26	10
	Sitting down	27	2	8	25	27	4
Getting OFF the toilet	Getting up	27	0	13	24	26	4
	Pivoting	22	0	18	22	12	24
	Getting on the wheelchair	11	0	24	6	9	26
Sum		124	5	95	115	113	90
Total		129		95	228		90

APPENDIX C

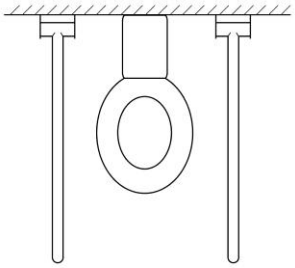
QUESTIONNAIRE

The user testing was approved by the institutional Review Board (IRB) for the sake of the risk and confidentiality of the subjects. I submitted a consent form, an advertisement flyer, and a questionnaire to IRB for review. Please refer to IRB for these materials (PI: Sanford, Jon Allen; Protocol number: H12014). I hereby attach the questionnaire because it is highly related to the testing process. The format of the following questionnaire has been modified to fit in this paper.

Part 1 (Trial 1- 4): Rate the grab bar

Trial _____

Grab bars without any attachment



1. How **HELPFUL** were these grab bars for getting **ON** the toilet?				
Very unhelpful	Unhelpful	Neutral	Helpful	Very Helpful
☐	☐	☐	☐	☐
2. How **SAFE** did you feel using these grab bars to get **ON** the toilet?				
Very Unsafe	Unsafe	Neutral	Safe	Very Safe
☐	☐	☐	☐	☐
3. How **EASY** were these grab bars for getting **ON** the toilet?				
Very Difficult	Difficult	Neutral	Easy	Very Easy

☐	☐	☐	☐	☐

4. How **COMFORTABLE** were these grab bars for getting **ON** the toilet?

Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable
☐	☐	☐	☐	☐

5. How **HELPFUL** were these grab bars for getting **OFF** the toilet?

Very unhelpful	Unhelpful	Neutral	Helpful	Very Helpful
☐	☐	☐	☐	☐

6. How **SAFE** did you feel using these grab bars to get **OFF** the toilet?

Very Unsafe	Unsafe	Neutral	Safe	Very Safe
☐	☐	☐	☐	☐

7. How **EASY** were these grab bars for getting **OFF** the toilet?

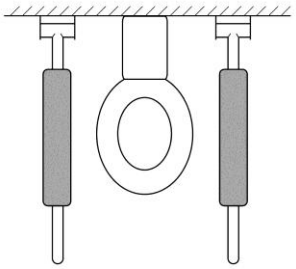
Very Difficult	Difficult	Neutral	Easy	Very Easy
☐	☐	☐	☐	☐

8. How **COMFORTABLE** were these grab bars for getting **OFF** the toilet?

Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable
☐	☐	☐	☐	☐

Trial _____

Grab bars with armrests

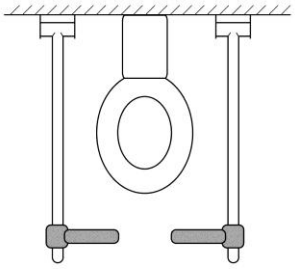


1. How **HELPFUL** were these armrests for getting **ON** the toilet?				
Very Helpless	Helpless	Neutral	Helpful	Very Helpful
☐	☐	☐	☐	☐
2. How **SAFE** did you feel using these armrests to get **ON** the toilet?				
Very Unsafe	Unsafe	Neutral	Safe	Very Safe
☐	☐	☐	☐	☐
3. How **EASY** were these armrests for getting **ON** the toilet?				
Very Difficult	Difficult	Neutral	Easy	Very Easy
☐	☐	☐	☐	☐
4. How **COMFORTABLE** were these armrests for getting **ON** the toilet?				
Very uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable
☐	☐	☐	☐	☐
5. How **HELPFUL** were these armrests for getting **OFF** the toilet?				
Very Helpless	Helpless	Neutral	Helpful	Very Helpful
☐	☐	☐	☐	☐
6. How **SAFE** did you feel using these armrests to get **OFF** the toilet?				
Very Unsafe	Unsafe	Neutral	Safe	Very Safe
☐	☐	☐	☐	☐
7. How **EASY** were these armrests for getting **OFF** the toilet?				
Very Difficult	Difficult	Neutral	Easy	Very Easy

☐	☐	☐	☐	☐
8. How **COMFORTABLE** were these armrests for getting **OFF** the toilet?				
Very uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable
☐	☐	☐	☐	☐
9. How would you rate the **WIDTH** of the armrests?				
Much Too Narrow	A Little Narrow	Just Right	A little Wide	Too Wide
☐	☐	☐	☐	☐
10. How would you rate the **LENGTH** of the armrests?				
Much Too Short	A little Short	Just Right	A little Long	Much Too Long
☐	☐	☐	☐	☐
11. How would you rate the **POSITION** of the armrests?				
Much Too Close To The Wall	A Little Close To The Wall	Just Right	A Little Far From The Wall	Much Too Far From The Wall
☐	☐	☐	☐	☐

Trial _____

Grab bars with short handles

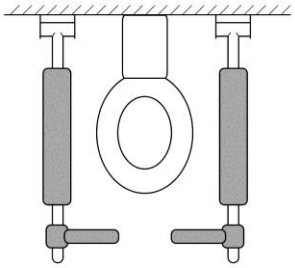


1. How **HELPFUL** were these short handles for getting **ON** the toilet?				
Very Helpless	Helpless	Neutral	Helpful	Very Helpful
☐	☐	☐	☐	☐
2. How **SAFE** did you feel using these short handles to get **ON** the toilet?				
Very Unsafe	Unsafe	Neutral	Safe	Very Safe
☐	☐	☐	☐	☐
3. How **EASY** were these short handles for getting **ON** the toilet?				
Very Difficult	Difficult	Neutral	Easy	Very Easy
☐	☐	☐	☐	☐
4. How **COMFORTABLE** were these short handles for getting **ON** the toilet?				
Very uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable
☐	☐	☐	☐	☐
5. How **HELPFUL** were these short handles for getting **OFF** the toilet?				
Very Helpless	Helpless	Neutral	Helpful	Very Helpful
☐	☐	☐	☐	☐
6. How **SAFE** did you feel using these short handles to get **OFF** the toilet?				
Very Unsafe	Unsafe	Neutral	Safe	Very Safe

☐	☐	☐	☐	☐
7. How **EASY** were these short handles for getting **OFF** the toilet?				
Very Difficult	Difficult	Neutral	Easy	Very Easy
☐	☐	☐	☐	☐
8. How **COMFORTABLE** were these short handles for getting **OFF** the toilet?				
Very uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable
☐	☐	☐	☐	☐
9. How would you rate the **DIAMETER** of the short handles?				
Much Too Small	A little Small	Just Right	A little Large	Too Large
☐	☐	☐	☐	☐
10. How would you rate the **LENGTH** of the short handles?				
Much Too Short	A little Short	Just Right	A little Long	Too Long
☐	☐	☐	☐	☐
11. Do you agree that the short handles were **EASY TO USE**?				
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
☐	☐	☐	☐	☐

Trial _____

Grab bars with both armrests and short handles



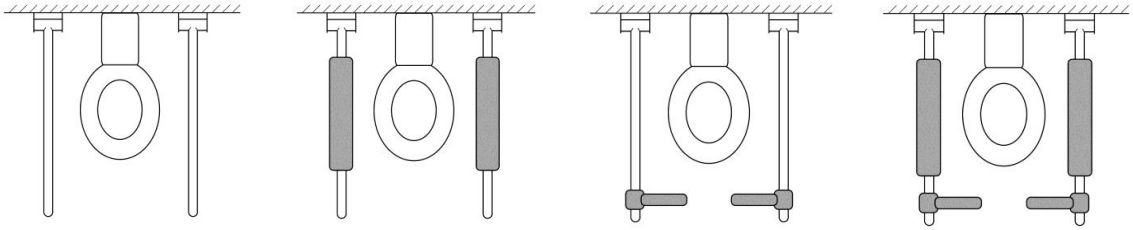
1. How **HELPFUL** were these grab bars for getting **ON** the toilet?				
Very unhelpful	Unhelpful	Neutral	Helpful	Very Helpful
☐	☐	☐	☐	☐
2. How **SAFE** did you feel using these grab bars to get **ON** the toilet?				
Very Unsafe	Unsafe	Neutral	Safe	Very Safe
☐	☐	☐	☐	☐
3. How **EASY** were these grab bars for getting **ON** the toilet?				
Very Difficult	Difficult	Neutral	Easy	Very Easy
☐	☐	☐	☐	☐
4. How **COMFORTABLE** were these grab bars for getting **ON** the toilet?				
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable
☐	☐	☐	☐	☐
5. How **HELPFUL** were these grab bars for getting **OFF** the toilet?				
Very unhelpful	Unhelpful	Neutral	Helpful	Very Helpful
☐	☐	☐	☐	☐
6. How **SAFE** did you feel using these grab bars to get **OFF** the toilet?				
Very Unsafe	Unsafe	Neutral	Safe	Very Safe
☐	☐	☐	☐	☐

7. How **EASY** were these grab bars for getting **OFF** the toilet?				
Very Difficult	Difficult	Neutral	Easy	Very Easy
☐	☐	☐	☐	☐

8. How **COMFORTABLE** were these grab bars for getting **OFF** the toilet?				
Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable
☐	☐	☐	☐	☐

Part 2: Comparison of grab bar configurations

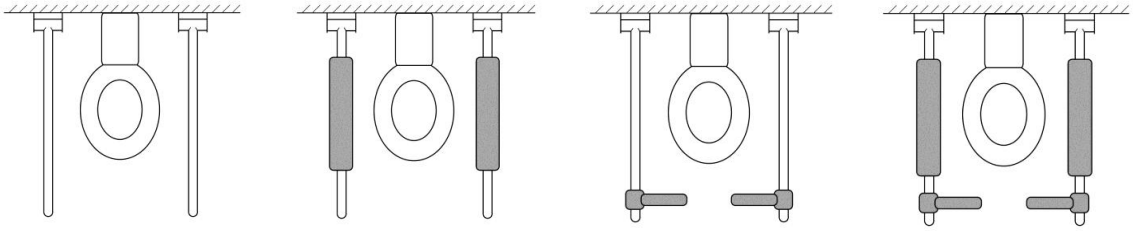
1. Please rank these four grab bar configurations <u>from most to least **SAFE** (from 1 to 4)</u>:



_____ _____ _____ _____

Reason:

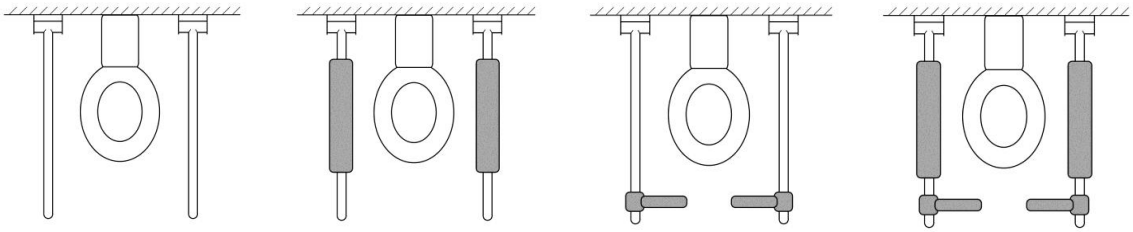
2. Please rank these four grab bar configurations <u>from most to least **EASY TO USE** (from 1 to 4):</u>



_____ _____ _____ _____

Reason:

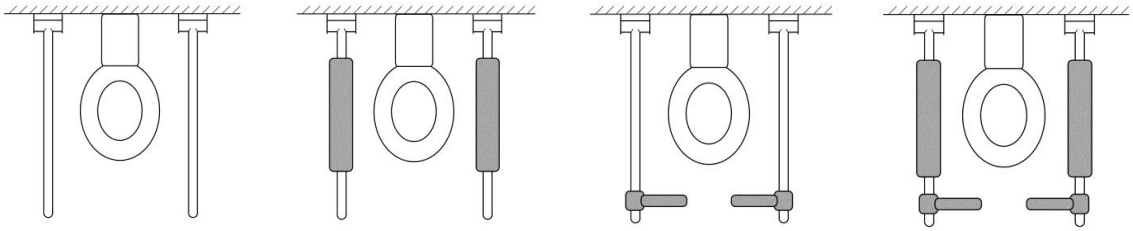
3. Please rank these four grab bar configurations <u>from most to least **COMFORTABLE TO USE** (from 1 to 4):</u>



_____ _____ _____ _____

Reason:

4. Which grab bar configuration do you think is the **OVERALL BEST**?



☐ ☐ ☐ ☐

Reason:

Trial 5: Find the best position for your preferred grab bars

How would you rate the height and the width of these grab bars?

Height _____				
Much Too low	A little low	Just Right	A little high	Too high
☐	☐	☐	☐	☐
Width _____				
Much Too narrow	A little narrow	Just Right	A little wide	Much Too wide
☐	☐	☐	☐	☐
Height _____				
Much Too low	A little low	Just Right	A little high	Too high
☐	☐	☐	☐	☐
Width _____				
Much Too narrow	A little narrow	Just Right	A little wide	Much Too wide
☐	☐	☐	☐	☐
Height _____				
Much Too low	A little low	Just Right	A little high	Too high
☐	☐	☐	☐	☐

Width _____				
Much Too narrow	A little narrow	Just Right	A little wide	Much Too wide
☐	☐	☐	☐	☐
The best position of your preferred grab bar configuration:				
Distance between the grab bars: _____ Height of the grab bars:_____				

Part 3: Questions and Concerns

1. Please tell us your likes and dislikes about the armrests in terms of safety, ease of use and comfort? Likes: Dislikes:
2. Please tell us your likes and dislikes about the short handles in terms of safety, ease of use and comfort? Likes: Dislikes:
3. Other questions?

APPENDIX D

TECHNICAL DRAWINGS

This part shows the original CAD drawings of the prototype. Figure D.1 to D.6 are drawings of the short handle. Figure D.7 to D.10 are drawings of the armrests. The prototype was built by assembling these parts. Hardware used in assembly includes screws, bolts, nuts, washers and detent springs.

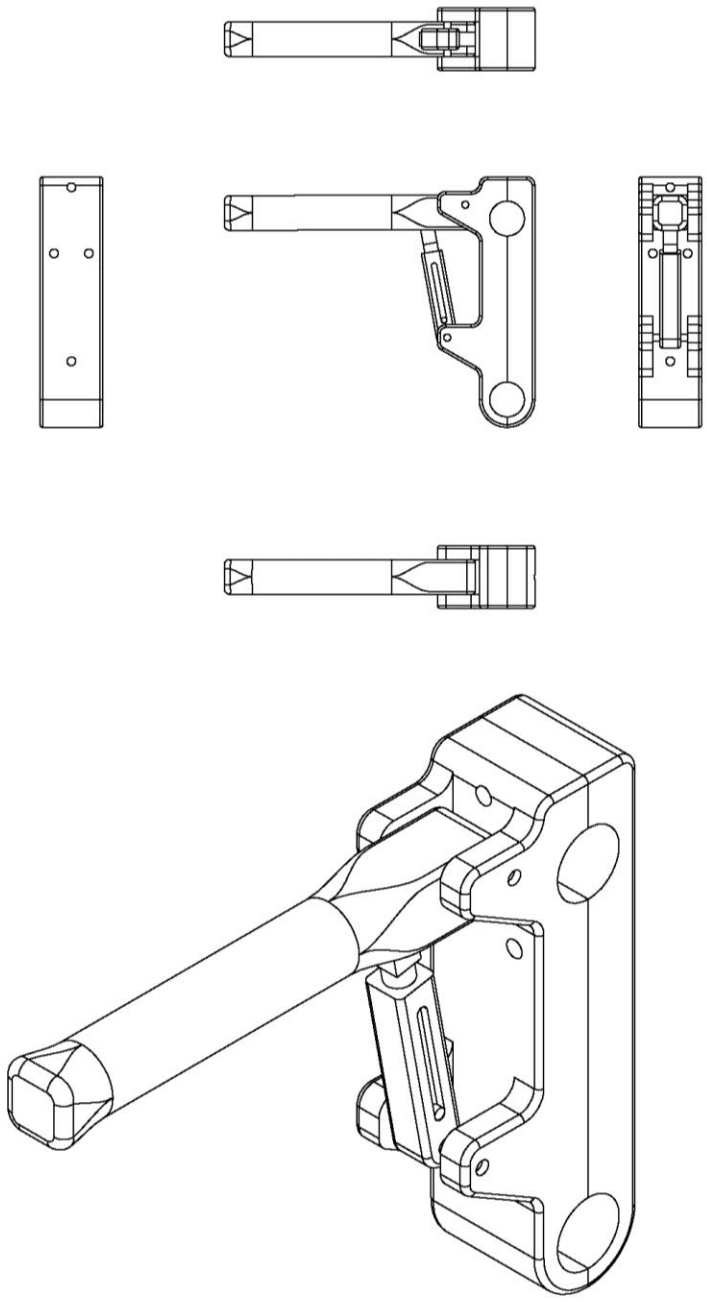


Figure D.1 Short Handle Assembly

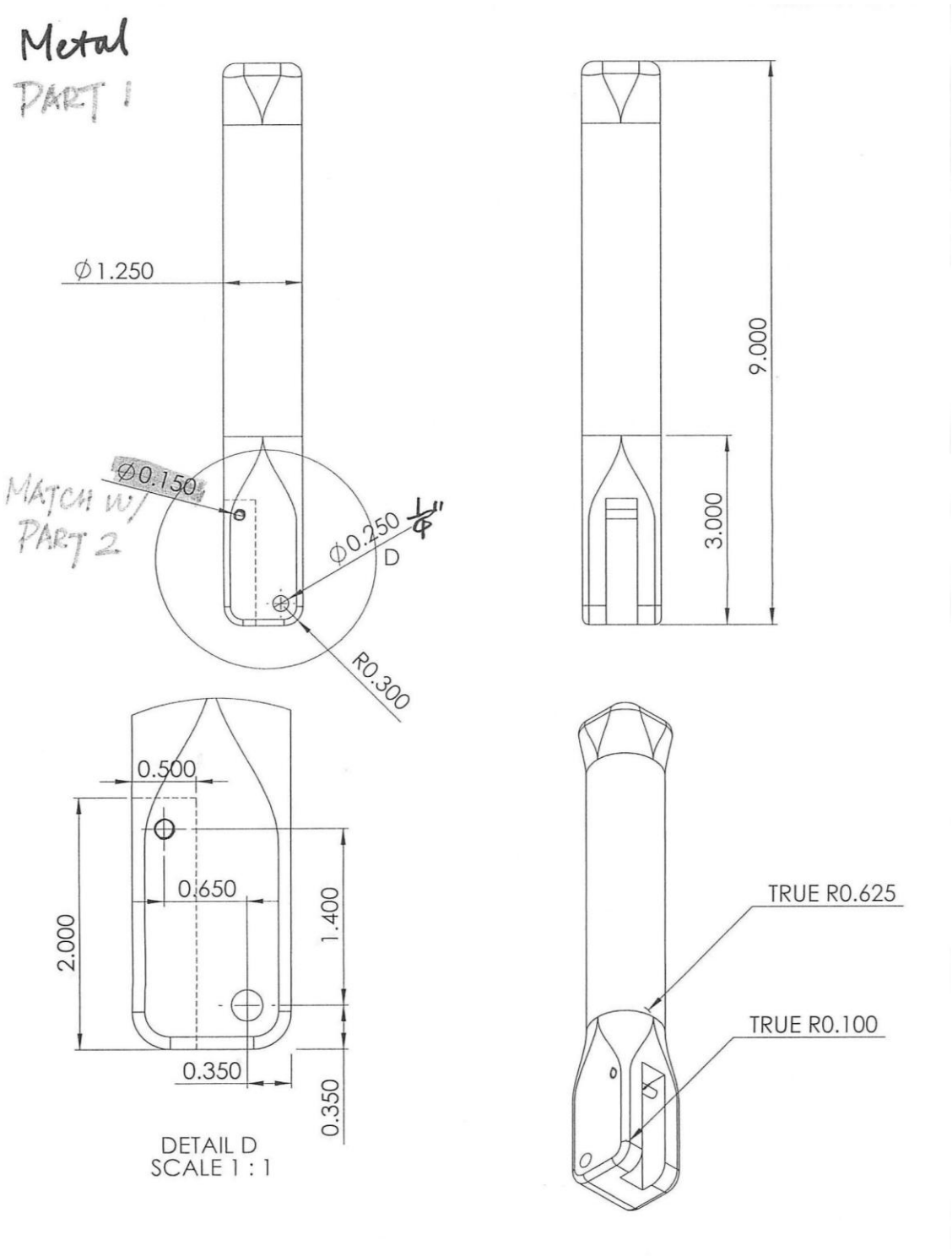


Figure D.2 Short Handle Part 1

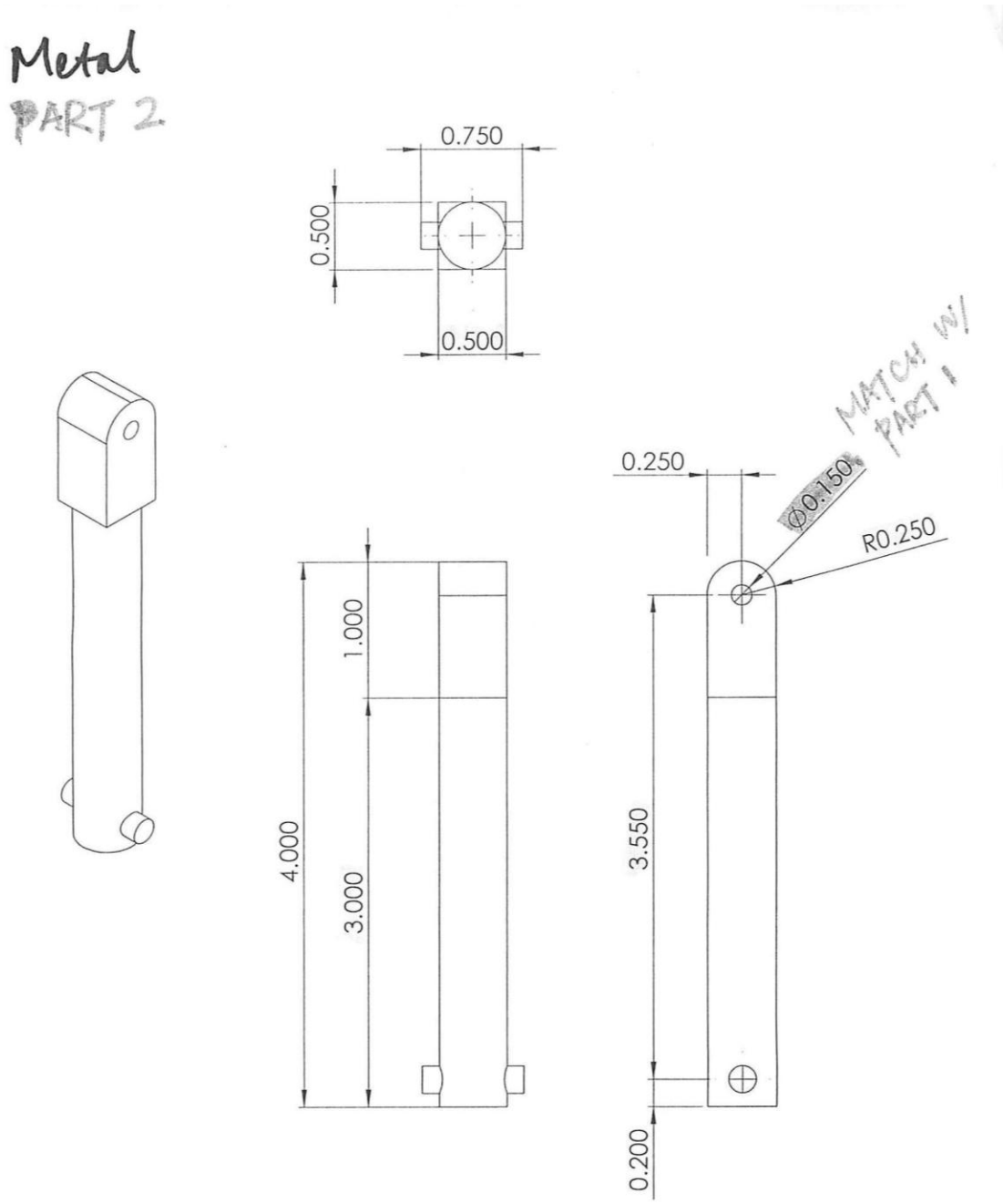


Figure D.3 Short Handle Part 2

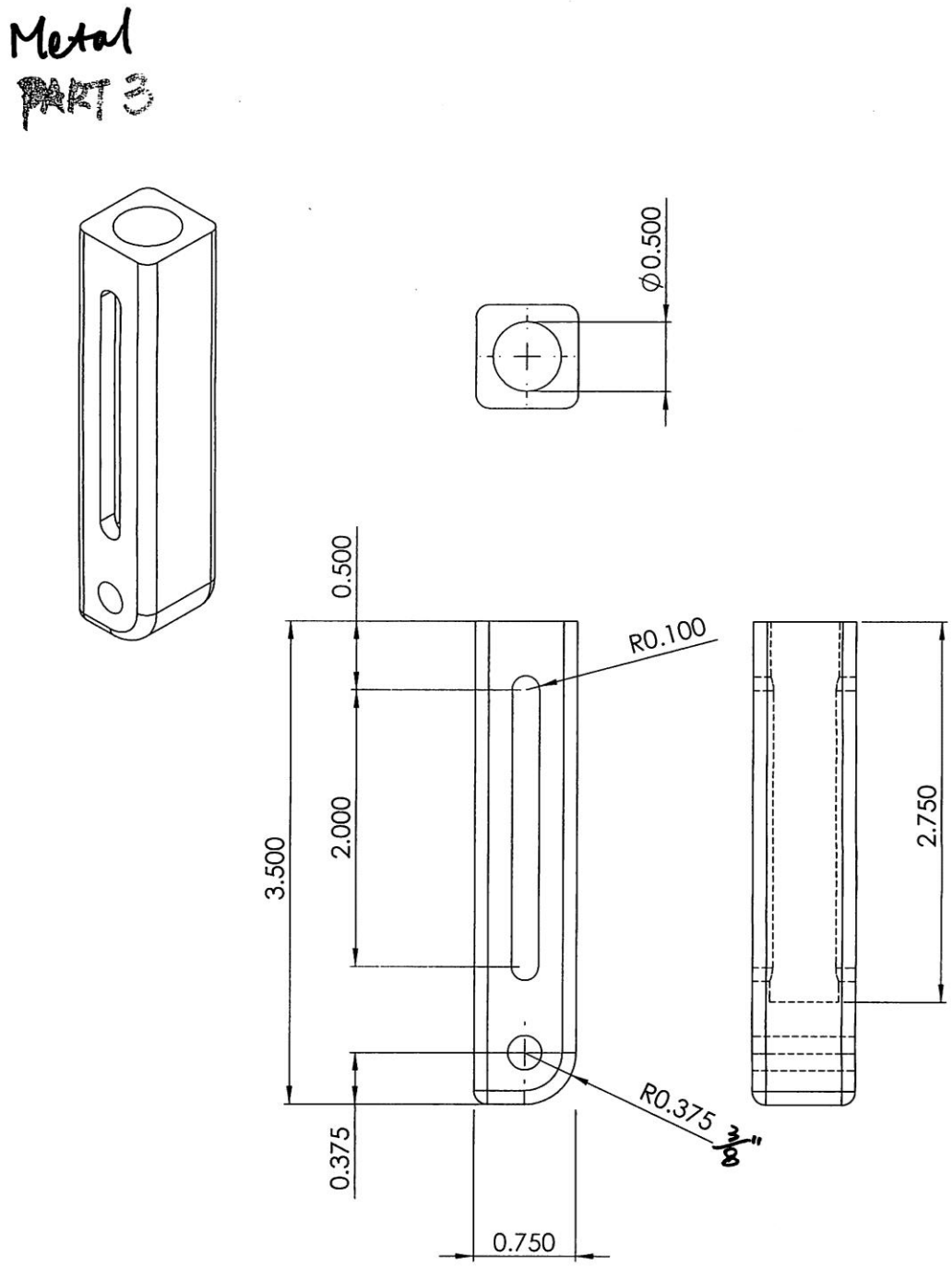


Figure D.4 Short Handle Part 3

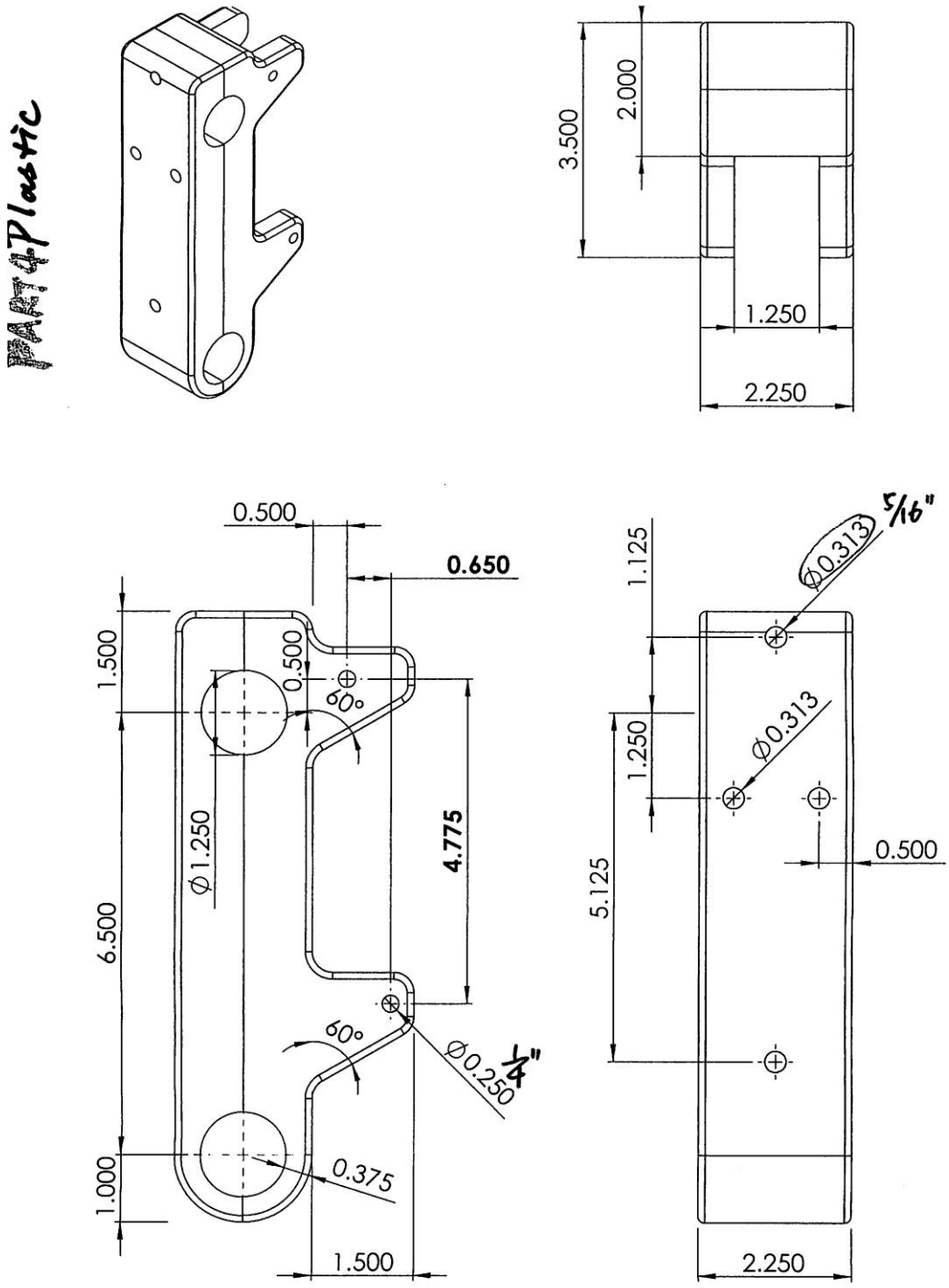


Figure D.5 Short Handle Part 4

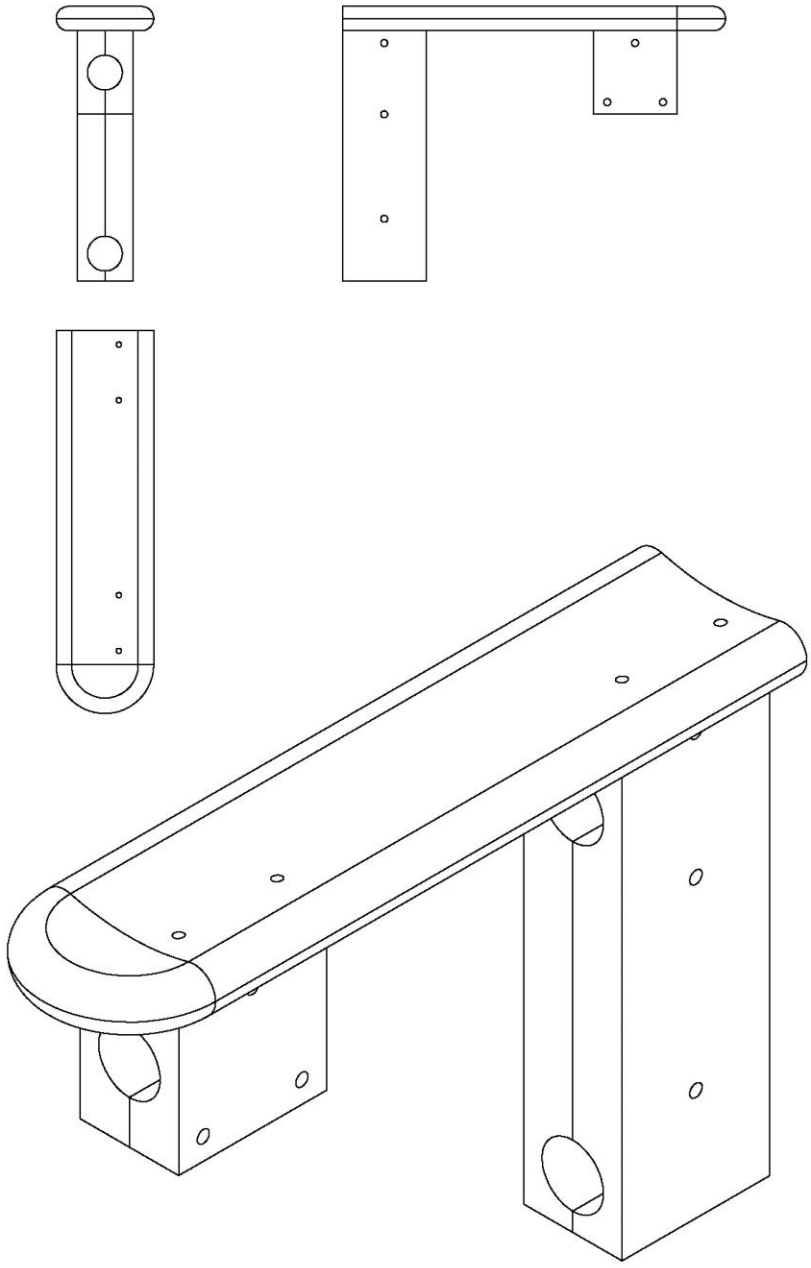


Figure D.6 Armrest Assembly

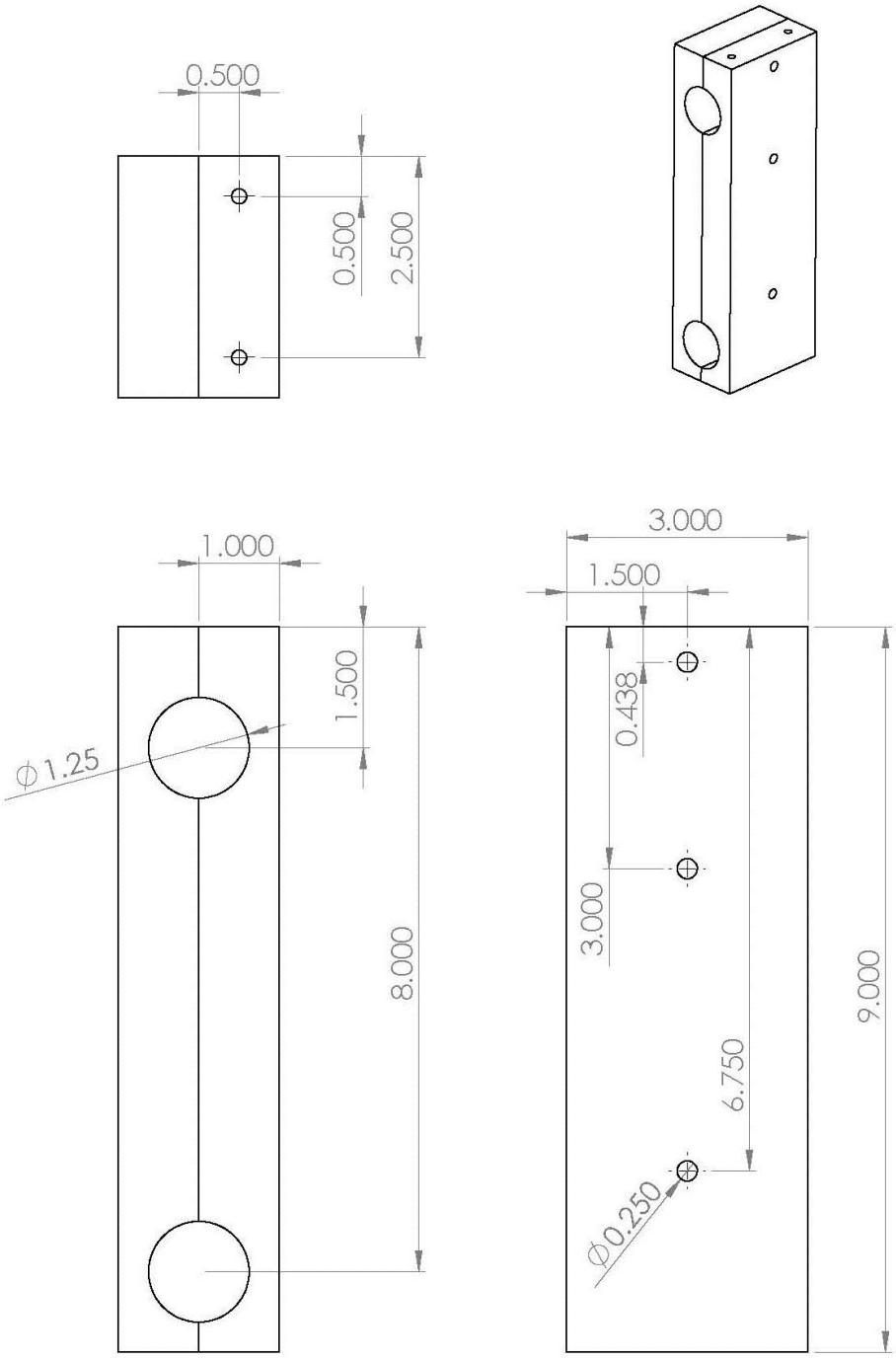


Figure D.7 Armrest Connecter Long

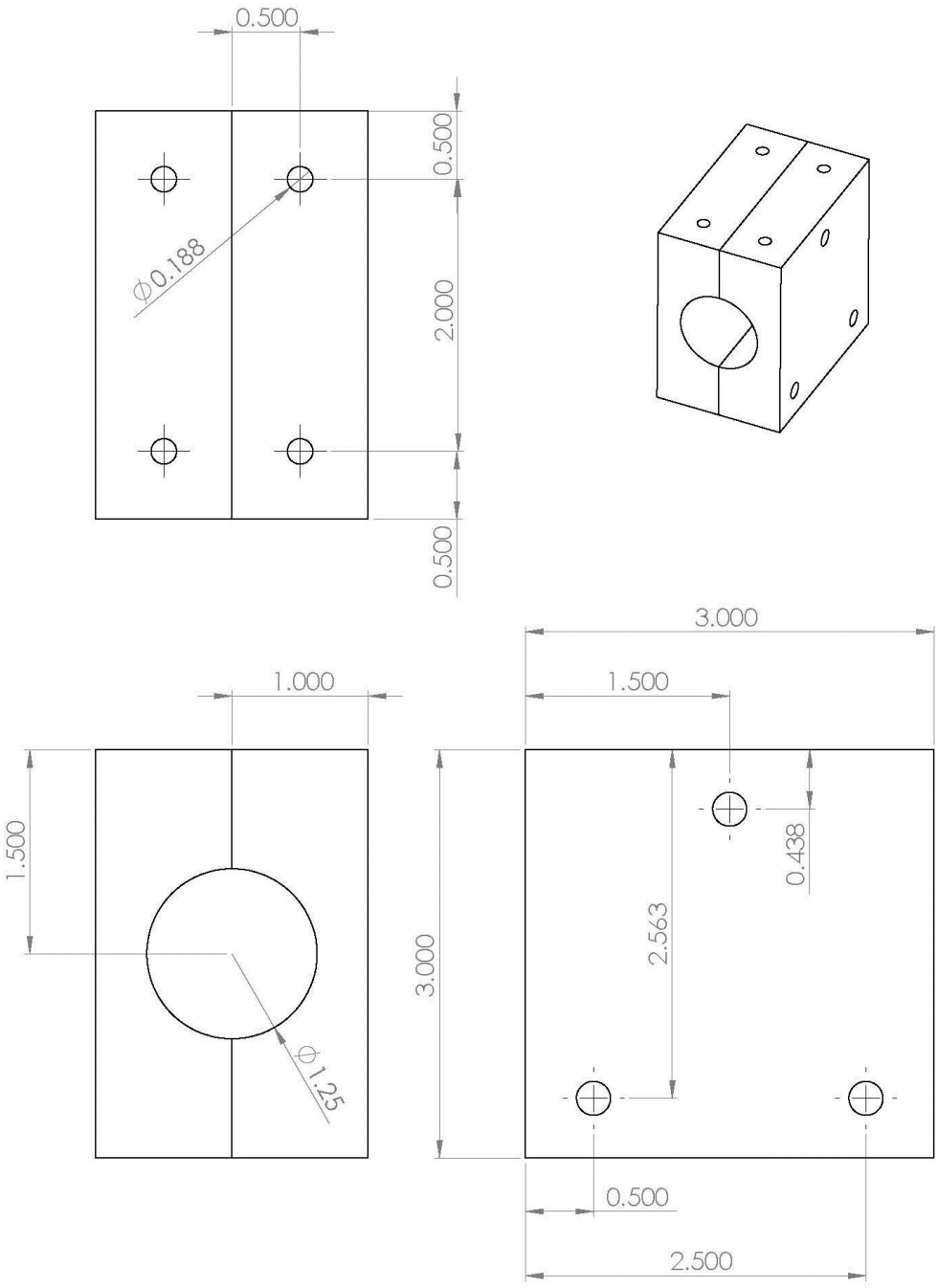


Figure D.8 Armrest Connecter Short

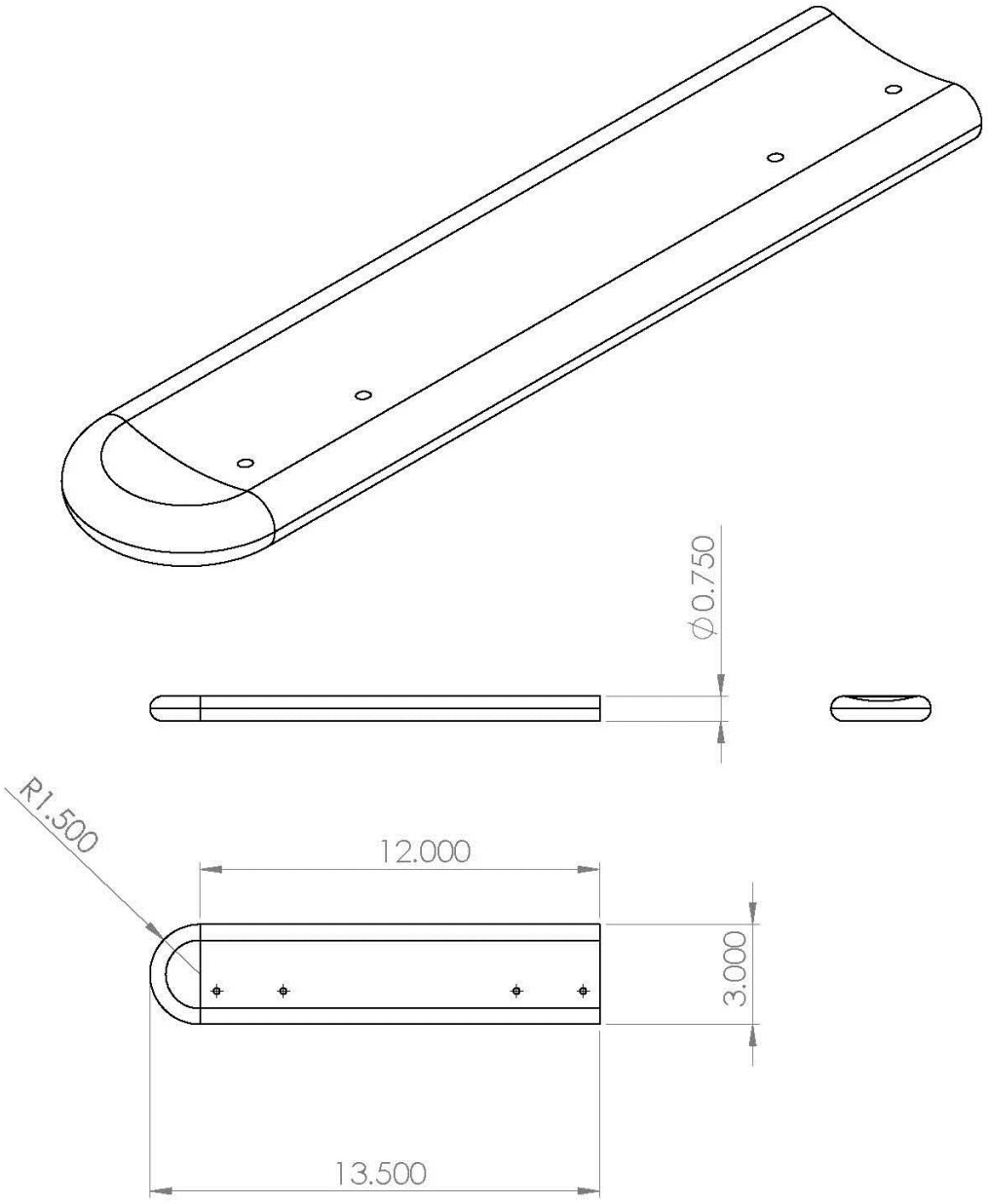


Figure D.9 Concaved Armrest

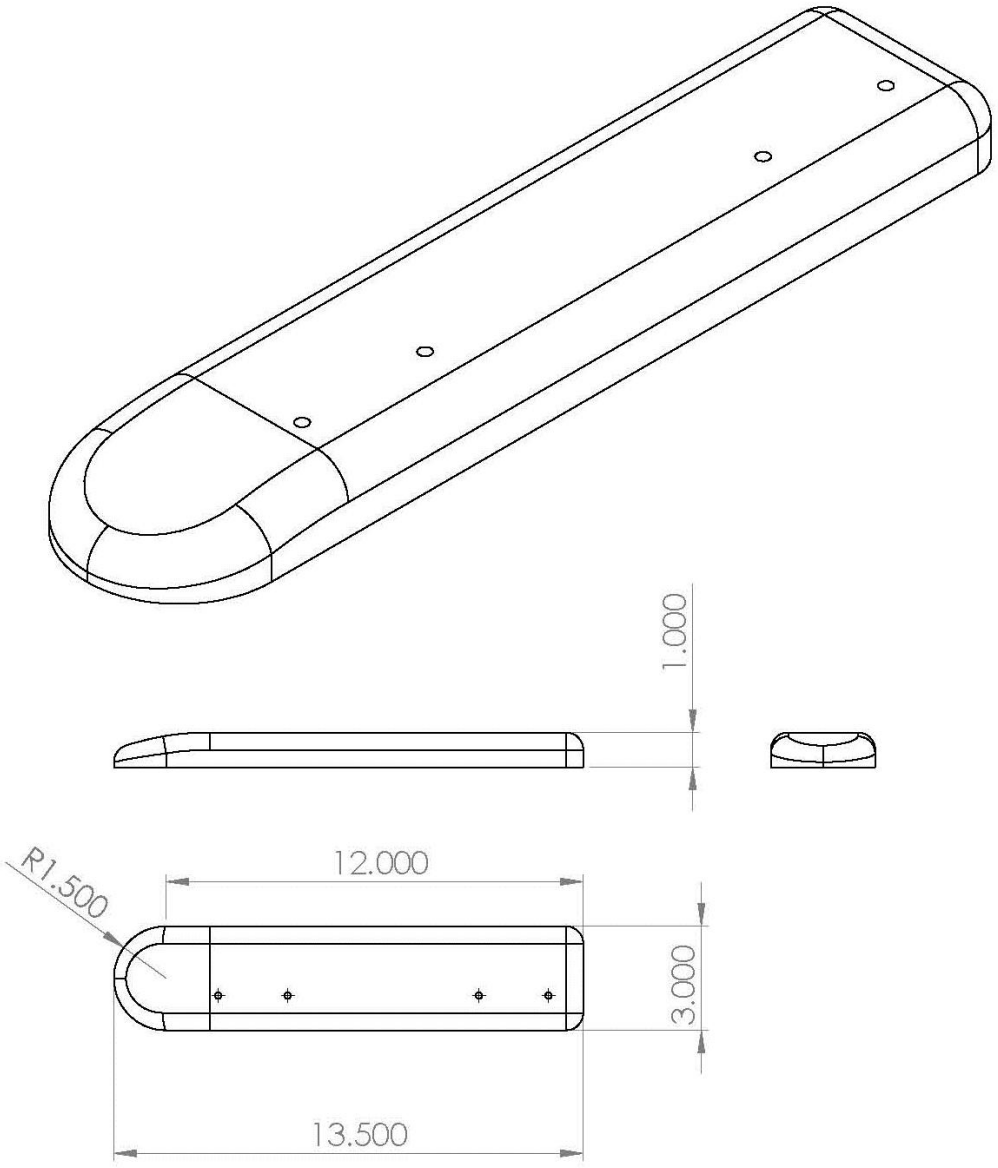


Figure D.10 Flat Armrest

APPENDIX E

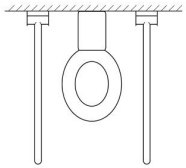
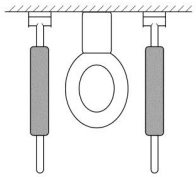
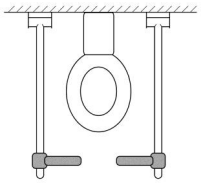
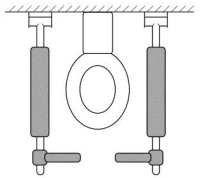
USER TESTING DATA

Please see following pages for data summaries of each subject.

Subject 1: Age 61, Female

Self Report – Rate the Grab Bars

Table E.1 Self Report - Rate the Grab Bars (Subject 1)

Questions	Configurations / Answers	Grab Bars without any attachments (GB)	Grab Bars with Armrests (GB+A)	Grab Bars with Short Handles (GB+SH)	Grab Bars with both Armrests and Short Handles (GB+A+SH)
					
Q1. How **HELPFUL** were these grab bars for **GETTING ON** the toilet?	Very helpless				
	Helpless				
	Neutral			√	
	Helpful	√			√
	Very Helpful		√		
Q2. How **SAFE** did you feel using these grab bars to **GET ON** the toilet?	Very unsafe				
	Unsafe				
	Neutral				
	Safe			√	
	Very Safe	√	√		√
Q3. How **EASY** were these grab bars for **GETTING ON** the toilet?	Very difficult				
	Difficult				
	Neutral			√	
	Easy				
	Very Easy	√	√		√
Q4. How **COMFORTABLE**	Very uncomfortable				

were these grab bars for **GETTING ON** the toilet?	Uncomfortable				
	Neutral			√	
	Comfortable	√			
	Very Comfortable		√		√
Q5. How **HELPFUL** were these grab bars for **GETTING OFF** the toilet?	Very helpless				
	Helpless				
	Neutral			√	
	Helpful				
	Very Helpful	√	√		√
Q6. How **SAFE** did you feel using these grab bars to **GET OFF** the toilet?	Very unsafe				
	Unsafe				
	Neutral				
	Safe			√	
	Very Safe	√	√		√
Q7. How **EASY** were these grab bars for **GETTING OFF** the toilet?	Very difficult				
	Difficult				
	Neutral			√	
	Easy				
	Very Easy	√	√		√
Q8. How **COMFORTABLE** were these grab bars for **GETTING OFF** the toilet?	Very uncomfortable				
	Uncomfortable				
	Neutral				
	Comfortable			√	
	Very Comfortable	√	√		√
Ranking by the subject: From Most to Least (From 1 to 4)	**Overall Best**		√		
	Safe	2	1	4	3
	Easy to Use	2	1	3	4
	Comfortable to use	2	1	4	3

G=Grab Bars; A=Armrests; W=Wheelchairs; SH=Short Handles.

Self Report – Questions and Concerns

Table E.2 Self Report – Questions and Concerns (Subject 1)

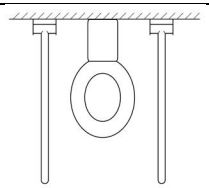
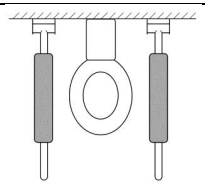
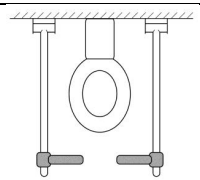
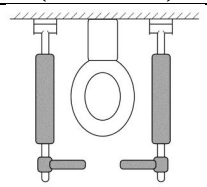
Q1. Please tell us your likes and dislikes about the **armrests** in terms of safety, ease of use and comfort?	Likes:	Nice smooth wood. The curve fit my arm perfectly. They were easy to grab, not too wide or too long.
	Dislikes:	None.
Q2. Please tell us your likes and dislikes about the **short handles** in terms of safety, ease of use and comfort?	Likes:	None.
	Dislikes:	I had to move them out of the way. I did not lean on them to transfer from the chair.
Q3. Other questions?	The grab bars are smooth and rounded. A good length + height. I like both upper and lower rails.	

This subject chose configuration GB+A as the overall best among the four configurations. This choice corresponds with her answers to questions 1 to 8. The rankings to the safety, ease of use, and comfort of each configuration also corresponds with her answers to questions 1 to 8. The two configurations that did not have the short handles were rated safer, easier and more comfortable to use than the two configurations that had the short handles.

The two armrests used in this testing have different profiles. One has flat top surface but curved down in the front. The other has a slightly curved concave on the top. This subject noticed this difference and stated that she preferred the one that has the concave (refer to her answers in section 1.2).

Observation Note (Taken based on the video records)

Table E.3 Transfer Aids that were used by Subject 1 in each step of transfers

Process of Toilet Transfer \ Configurations		Grab Bars without any attachments (GB) 	Grab Bars with Armrests (GB+A) 	Grab Bars with Short Handles (GB+SH) 	Grab Bars with both Armrests and Short Handles (GB+A+SH) 
Getting on the toilet	Standing up from the wheelchair	GB with/without W	GB **A**	GB with/without W	GB **A** with/without W
	Pivoting	GB	GB **A** with/without W	GB with/without W	**A** with/without **SH**
	Sitting down on the toilet	GB	GB **A**	GB	**A** with/without **SH**
Getting off the toilet	Standing up from the toilet	GB	GB	GB with/without W	**A** GB W
	Pivoting	GB W	GB **A** with/without W	GB with/without W	**A** GB With/without W
	Sitting down in the wheelchair	W	GB **A** W	GB with/without W	**A** GB With/without W

G=Grab Bars; A=Armrests; W=Wheelchairs; SH=Short Handles.

This chart shows all the transfer aids that were used by the subject when he/she transferred between the wheelchair and the toilet. For each configuration, the subject tried 2 to 3 times transferring on and off the toilet. So when the transfer aid was not used every time, there is a "with/without" in front of it.

Analysis

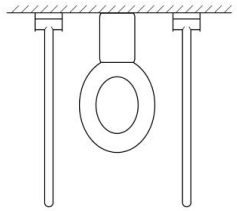
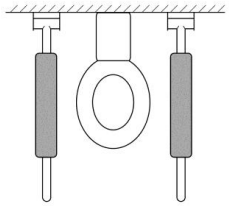
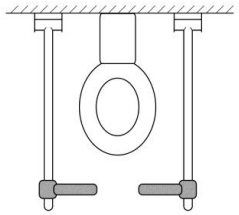
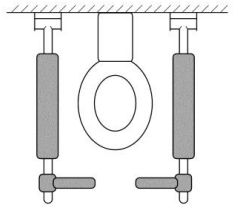
Subject 1 was short and wide. She had more weight on her upper body. The subject said that she had very weak wrists, so she tried not to use her wrists. It was noticeable that she often rested her forearms on grab bars, armrests, or the wheelchair armrests. In the two configurations that have armrests, she used the armrests very often. She liked the configuration GB (grab bars without any attachments), but found out that configuration GB+A (grab bars with arm rests) was the best for her. Because she can lean her forearms on the armrests, which she felt more comfortable and easier rather than just using her hands.

She tried to use the short handles, but later on she found out that those short handles were not suitable for her. From the video we can see that she put her hands on the short handles and tried to push or pull, but she ended up moving them out of the way.
For each configuration, this subject tried to use the grab bars and the attachments in different ways in order to figure out which way is better. If we look at how she got on and off the toilet regardless of what transfer aid she used, there were mainly two approaches. Approach 1 was to use grab bars/armrests on one side. Approach 2 was to use grab bars/armrests on both sides. The subject needed more support from the wheelchair using approach 1 than using approach 2. But she spent less time completing the transfer in approach 1 than in approach 2.

Subject 2: Age 77, Male

Self Report – Rate the Grab Bars

Table E.4 Self Report – Rate the Grab Bars (Subject 2)

Questions	Configurations / Answers	Grab Bars without any attachments (GB)	Grab Bars with Armrests (GB+A)	Grab Bars with Short Handles (GB+SH)	Grab Bars with both Armrests and Short Handles (GB+A+SH)
					
Q1. How **HELPFUL** were these grab bars for **GETTING ON** the toilet?	Very helpless				
	helpless				
	Neutral		√		
	Helpful	√			
	Very Helpful			√	√
Q2. How **SAFE** did you feel using these grab bars to **GET ON** the toilet?	Very unsafe				
	Unsafe				
	Neutral		√		
	Safe				
	Very Safe	√		√	√
Q3. How **EASY** were these grab bars for **GETTING ON** the toilet?	Very difficult				
	Difficult				
	Neutral	√	√		
	Easy				
	Very Easy			√	√
Q4. How	Very				

COMFORTABLE were these grab bars for **GETTING ON** the toilet?	uncomfortable				
	Uncomfortable				
	Neutral		√		
	Comfortable	√			
	Very Comfortable			√	√
Q5. How **HELPFUL** were these grab bars for **GETTING OFF** the toilet?	Very helpless				
	Helpless		√		
	Neutral	√			
	Helpful				
	Very Helpful			√	√
Q6. How **SAFE** did you feel using these grab bars to **GET OFF** the toilet?	Very unsafe				
	Unsafe				
	Neutral	√	√		
	Safe				
	Very Safe			√	√
Q7. How **EASY** were these grab bars for **GETTING OFF** the toilet?	Very difficult				
	Difficult				
	Neutral		√		
	Easy	√			
	Very Easy			√	√
Q8. How **COMFORTABLE** were these grab bars for **GETTING OFF** the toilet?	Very uncomfortable				
	Uncomfortable				
	Neutral	√	√		
	Comfortable				
	Very Comfortable			√	√
Ranking by the subject: From Most to Least (From 1 to 4)	Overall Best			√	
	Safe	3	4	1	2
	Easy to Use	3	4	1	2
	Comfortable to use	3	4	1	2

G=Grab Bars; A=Armrests; W=Wheelchairs; SH=Short Handles.

Questions and Concerns

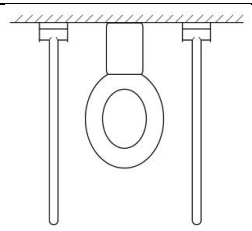
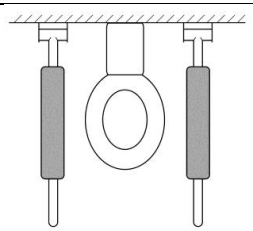
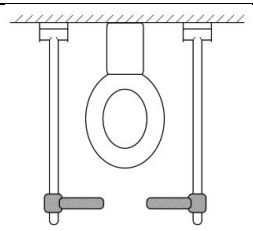
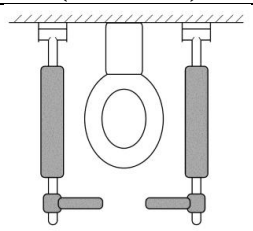
Table E.5 Self Report – Questions and Concerns (Subject 2)

Q1. Please tell us your likes and dislikes about the **armrests** in terms of safety, ease of use and comfort?	Likes:	Did not care for the armrest.
	Dislikes:	None.
Q2. Please tell us your likes and dislikes about the **short handles** in terms of safety, ease of use and comfort?	Likes:	The short handles were convenient and helpful.
	Dislikes:	None.
Q3. Other questions?	None.	

This subject stated that he did not care for the armrests. As such, his attitude towards the armrests was mostly neutral in questions 1 to 8. This subject chose configuration GB+SH as the overall best for him. This choice corresponds with his answers to questions 1 to 8. The ranking to the safety, ease of use, and comfort of each configuration also corresponds with his answers to questions 1 to 8. The two configurations that had the short handles were rated safer, easier and more comfortable to use than configurations that did not have the short handles.

Observation Note (Taken based on the video records)

Table E.6 Transfer Aids that were used by Subject 2 in each step of transfers

Process of Toilet Transfer \ Configurations		Grab Bars without any attachments (GB)	Grab Bars with Armrests (GB+**A**)	Grab Bars with Short Handles (GB+**SH**)	Grab Bars with both Armrests and Short Handles (GB+**A**+**SH**)
					
Getting on the toilet	Standing up from the wheelchair	GB with/without W	GB With/without W	**SH**	W With/without **SH**
	Pivoting	GB	GB **A**	GB	**A** **SH** With/without W
	Sitting down on the toilet	GB	**A** or GB	GB	**A**
Getting off the toilet	Standing up from the toilet	GB	GB	**SH** With/without GB	**SH** With/ without GB
	Pivoting	GB W	GB W	GB with/without W	GB W
	Sitting down in the wheelchair	W	W	**SH**	W

G=Grab Bars; A=Armrests; W=Wheelchairs; SH=Short Handles.

This chart shows all the transfer aids that were used by the subject when he/she transferred between the wheelchair and the toilet. For each configuration, the subject tried 2 to 3 times transferring on and off the toilet. So when the transfer aid was not used every time, there is a "with/without" in front of it.

Analysis

Subject 2 had an average height and width. He had more weight on his upper body, especially his belly. He mainly used the short handles to help him stand up from the toilet. He also used these short handles to get out from the wheelchair, but he sometimes used the wheelchair too.

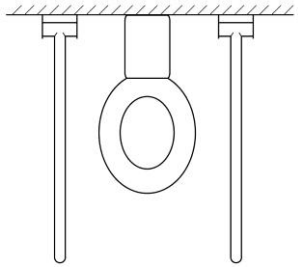
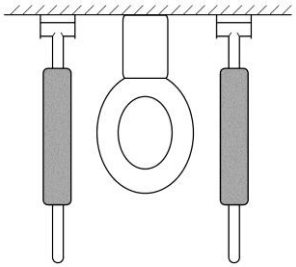
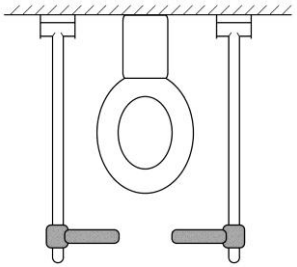
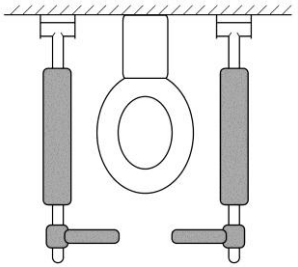
Although this subject put his hands on the armrests in some steps, he did not care for the armrests, as he stated in his questionnaire. It was just because the armrests were mounted on the place where he needed to put his hands on. Without the armrests, he could put his hands on the grab bars.

It is also noticeable that when the subject got more familiar with the configurations, he used them in a way that was more suitable for him. For example, when he stood up from the toilet in configuration GB+ SH, he lifted up the short handle on his left side and kept the other handle down. He did not lift up the handle that was down when he was turning around and sitting back to the wheelchair.

Subject 3: Age 74, Female

Self Report – Rate the grab bars

Table E.7 Self Report – Rate the Grab Bars (Subject 3)

Questions	Configurations / Answers	Grab Bars without any attachments (GB)	Grab Bars with Armrests (GB+A)	Grab Bars with Short Handles (GB+SH)	Grab Bars with both Armrests and Short Handles (GB+A+SH)
					
Q1. How **HELPFUL** were these grab bars for **GETTING ON** the toilet?	Very helpless				
	helpless		√		
	Neutral				
	Helpful	√			
	Very Helpful			√	√
Q2. How **SAFE** did you feel using these grab bars to **GET ON** the toilet?	Very unsafe				
	Unsafe				
	Neutral		√		
	Safe	√			
	Very Safe			√	√
Q3. How **EASY** were these grab bars for **GETTING ON**	Very difficult				
	Difficult				
	Neutral		√		

the toilet?	Easy	√			
	Very Easy			√	√
Q4. How **COMFORTABLE** were these grab bars for **GETTING ON** the toilet?	Very uncomfortable				
	Uncomfortable				
	Neutral		√		
	Comfortable	√			
	Very Comfortable			√	√
Q5. How **HELPFUL** were these grab bars for **GETTING OFF** the toilet?	Very helpless				
	Helpless				
	Neutral		√		
	Helpful	√			
	Very Helpful			√	√
Q6. How **SAFE** did you feel using these grab bars to **GET OFF** the toilet?	Very unsafe				
	Unsafe				
	Neutral		√		
	Safe				
	Very Safe	√		√	√
Q7. How **EASY** were these grab bars for **GETTING OFF** the toilet?	Very difficult				
	Difficult				
	Neutral		√		
	Easy	√			
	Very Easy			√	√
Q8. How **COMFORTABLE** were these grab bars for **GETTING OFF** the toilet?	Very uncomfortable				
	Uncomfortable				
	Neutral		√		
	Comfortable				
	Very Comfortable	√		√	√
Ranking by the subject	Overall Best			√	
	Safe	2	2	1	1

From Most to Least (From 1 to 4)	Easy to Use	2	2	1	1
	Comfortable to use	2	2	1	1

G=Grab Bars; A=Armrests; W=Wheelchairs; SH=Short Handles.

Self Report – Questions and Concerns

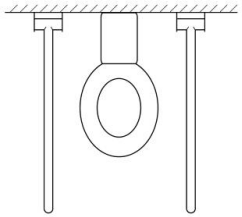
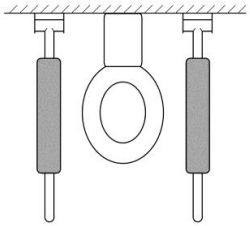
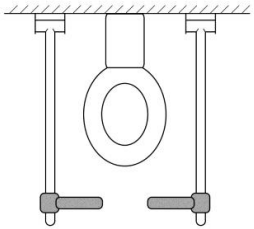
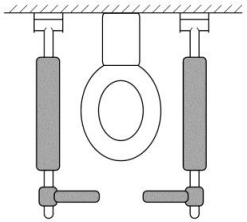
Table E.8 Self Report – Questions and Concerns (Subject 3)

Q1. Please tell us your likes and dislikes about the **armrests** in terms of safety, ease of use and comfort?	Likes:	I like armrest + hand bars, they are very safe and convenient.
	Dislikes:	None.
Q2. Please tell us your likes and dislikes about the **short handles** in terms of safety, ease of use and comfort?	Likes:	None.
	Dislikes:	None.
Q3. Other questions?	No. very good job.	

The subject chose configuration GB+SH to be the overall best. This choice corresponds with her answers to questions 1 to 8. When asked to rate the safety, ease of use, comfort of the four configurations, subject 3 rated both configurations that had short handles (GB+SH and GB+A+SH) as the most safe, easy to use, comfortable. She did not think there was any difference between these two configurations. Also for the two configurations that did not have the short handles (GB and GB+A), she did not state any difference between them. But if we look at the answers she gave to question 1 to 8, we can find out that configuration GB was better in all aspects than configuration GB+A.

Observation Note (Taken Based on the video records)

Table E.9 Parts of grab bars that were used by Subject 3 in each step of transfers

Process of Toilet Transfer \ Configurations		Grab Bars without any attachments (GB)	Grab Bars with Armrests (GB+A)	Grab Bars with Short Handles (GB+SH)	Grab Bars with both Armrests and Short Handles (GB+A+SH)
					
Getting on the toilet	Standing up from the wheelchair	GB	GB	**SH**	**SH**
	Pivoting	GB	GB **A**	**SH**	**SH**
	Sitting down on the toilet	GB	GB	**SH**	**SH**
Getting off the toilet	Standing up from the toilet	GB	GB	**SH**	**SH**
	Pivoting	GB W	GB W	**SH** W	**SH**
	Sitting down in the wheelchair	W	W	**SH** with/without W	**SH**

G=Grab Bars; A=Armrests; W=Wheelchairs; SH=Short Handles.

This chart shows all the transfer aids that were used by the subject when he/she transferred between the wheelchair and the toilet. For each configuration, the subject tried 2 to 3 times transferring on and off the toilet. So when the transfer aid was not used every time, there is a “with/without” in front of it.

Analysis

Subject 3 was tall, not too wide nor narrow. Her body weight was more evenly contributed than others.

The short handles were used by this subject all the time when they are mounted on the grab bars. And when the short handles were installed, the grab bars and the wheelchair were used much less often. Especially when the subject was getting off the toilet, she used Grab Bars and the Wheelchair in configuration GB and GB+A, but she switched to use the short handles and the wheelchair in configuration GB+SH. In configuration GB+A+SH, the subject only used the short handles.

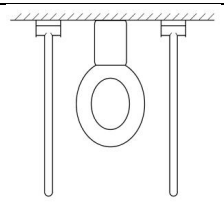
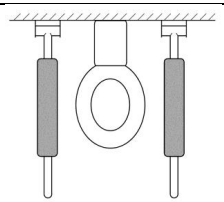
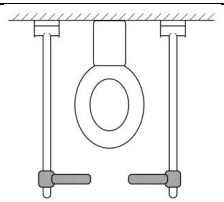
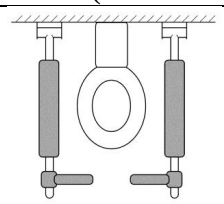
While she was turning around, she used the short handle that was up as a pivoting axis. She kept the other short handle down and grabbed on it until her hand had to move to somewhere else.

The armrests were seldom used by this subject.

Subject 4: Age 82, Female

Self Report – Rate the grab bars

Table E.10 Self Report – Rate the Grab Bars (Subject 4)

Questions	Configurations / Answers	Grab Bars without any attachments (GB)	Grab Bars with Armrests (GB+A)	Grab Bars with Short Handles (GB+SH)	Grab Bars with both Armrests and Short Handles (GB+A+SH)
					
Q1. How **HELPFUL** were these grab bars for **GETTING ON** the toilet?	Very helpless				
	helpless				
	Neutral				
	Helpful			√	√
	Very Helpful	√	√		
Q2. How **SAFE** did you feel using these grab bars to **GET ON** the toilet?	Very unsafe				
	Unsafe				
	Neutral				
	Safe			√	√
	Very Safe	√	√		
Q3. How **EASY** were these grab bars for **GETTING ON** the toilet?	Very difficult				
	Difficult				
	Neutral				
	Easy			√	√
	Very Easy	√	√		

Q4. How **COMFORTABLE** were these grab bars for **GETTING ON** the toilet?	Very uncomfortable				
	Uncomfortable				
	Neutral				
	Comfortable			√	√
	Very Comfortable	√	√		
Q5. How **HELPFUL** were these grab bars for **GETTING OFF** the toilet?	Very helpless				
	Helpless				
	Neutral				
	Helpful			√	√
	Very Helpful	√	√		
Q6. How **SAFE** did you feel using these grab bars to **GET OFF** the toilet?	Very unsafe				
	Unsafe				
	Neutral				
	Safe			√	√
	Very Safe	√	√		
Q7. How **EASY** were these grab bars for **GETTING OFF** the toilet?	Very difficult				
	Difficult				
	Neutral				
	Easy			√	√
	Very Easy	√	√		
Q8. How **COMFORTABLE** were these grab bars for **GETTING OFF** the toilet?	Very uncomfortable				
	Uncomfortable				
	Neutral				
	Comfortable			√	√
	Very Comfortable	√	√		
Ranking by the subject From Most to Least (From 1 to 4)	Overall Best				√
	Safe	4	3	2	1
	Easy to Use	4	3	2	1
	Comfortable to use	4	3	2	1

Self Report – Questions and Concerns

Table E.11 Self Report – Questions and Concerns (Subject 4)

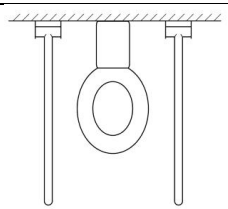
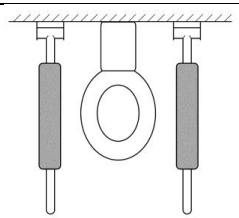
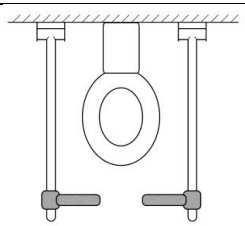
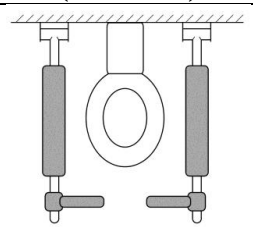
Q1. Please tell us your likes and dislikes about the **armrests** in terms of safety, ease of use and comfort?	Likes:	I love them. I prefer the one on the left that doesn't have the concave.
	Dislikes:	None.
Q2. Please tell us your likes and dislikes about the **short handles** in terms of safety, ease of use and comfort?	Likes:	None.
	Dislikes:	They are comfortable. But I don't think they are necessary.
Q3. Other questions?	Neat idea. It's needed.	

This subject chose configuration GB+S+SH as the best one after she used all the four configurations. But she stated that she loved the armrests and did not think the short handles were necessary. If we look at this subject's answers to questions 1 to 8, configurations GB and GB+A were better in all aspects than configuration GB+SH and GB+A+SH. So we might guess that configuration GB+A was the overall best for her.

The two armrests used in this testing have different profiles. One has flat top surface but curved down in the front. The other has a slightly curved concave on the top. This subject noticed this difference and stated that she preferred the one that does not have the concave (refer to her answers in section 1.2). The reason was that she had to put her forearm parallel to the armrest that had the concave, which she thought was less flexible to use than using the armrest that does not have the concave.

Observation Note (Taken Based on the video records)

Table E.12 Parts of grab bars that were used by Subject 4 in each step of transfers

Process of Toilet Transfer / Configurations		Grab Bars without any attachments (GB)	Grab Bars with Armrests (GB+A)	Grab Bars with Short Handles (GB+SH)	Grab Bars with both Armrests and Short Handles (GB+A+SH)
					
Getting on the toilet	Standing up from the wheelchair	GB	GB	**SH**	**SH** GB
	Pivoting	GB	GB **A** With/without W	**SH**	**SH** **A**
	Sitting down on the toilet	GB	GB or **A**	**SH**	**A**
Getting off the toilet	Standing up from the toilet	GB	**A** or GB	**SH**	GB or **SH**
	Pivoting	GB	GB **A**	**SH**	**SH**
	Sitting down in the wheelchair	GB	GB	**SH**	**SH** with/without W

G=Grab Bars; A=Armrests; W=Wheelchairs; SH=Short Handles.

This chart shows all the transfer aids that were used by the subject when he/she transferred between the wheelchair and the toilet. For each configuration, the subject tried 2 to 3 times transferring on and off the toilet. So when the transfer aid was not used every time, there is a "with/without" in front of it.

Analysis

Subject 4 was wide, and has an average height. She was overall heavier than the average and had more weight on her upper body.

This subject used the short handles very often. She mainly used them for support when she turned around. In configuration GB+A+SH, she tried to use these handles to stand up, but she showed difficulty and doubted the purpose of the short handles. It looked like the short handles were located too close to her chest, even closer than her feet, so she could not use them for standing up. But she succeeded standing up using these short handles in configuration GB+SH. She also suggested that for somebody who has arthritis and needs to rest in a standing position the short handles may be useful.

The armrests were comfortable for her to rest her arms when she sat on the toilet. She also pushed on the armrests when she stood up from the toilet.

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